Sandia Corporation

Bibliography

IMPACT PHYSICS

by

Robert Graham

DECEMBER 1958

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SANDIA CORPORATION BIBLIOGRAPHY

IMPACT PHYSICS

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Robert Graham
Physical Research Department
Sandia Corporation

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ABSTRACT

This bibliography consists of a rather complete collection of references and abstracts on the subjects of: (1) plastic wave propagation in bounded solids; (2) behavior of metals under explosive conditions; (3) dynamic photoelasticity; (4) penetration phenomena. Other topics covered in less detail are: (5) behavior of material at high strain rates; (6) lateral impact; (7) impact measurement devices.

General references at the beginning of the bibliography cite articles or books which cover the field of impact. An author index and a chronological listing of articles within a particular topic are included.

PREFACE

The Physical Research Department at Sandia Corporation has encountered many impact problems in its past and current activities. In order to become familiar with past work in this field, a systematic search and study of the literature was undertaken. This bibliography is the result of the literature search and is being published since comparison with other bibliographies shows it to be more complete in certain areas.

The subject of wave propagation is an important consideration in most impact problems but it was decided not to search the literature for articles dealing with wave propagation, as such, since this extensive field is the subject of several recent survey articles and books.[1, 2, 3, 6, 7, 8*]

The bibliography in its final form deals with wave propagation as it applies to specific areas of interest in impact problems. The references have been assembled into groups according to the main topic of the reference. The major subjects included in the bibliography are:

1. Plastic Wave Propagation in Bounded Solids
2. Behavior of Metals Under Explosive Conditions
3. Dynamic Photoelasticity and Related Topics
4. Penetration Phenomena

All of the references listed under these subjects are articles which are technically related and which normally follow the same general trend of thought in the literature. These subjects are felt to be well developed in the bibliography. That is, the references listed can be considered as representing a high percentage of the total references on this subject. To obtain this extensive coverage a search was made of the indexes of well known applied mechanics and physics publications. The articles listed in these indexes were then obtained and the references in each article were added to the bibliography. This new list of references was searched for more references, this method being continued until the list of references given by the various articles converged.

The subjects listed below are also included in this bibliography but do not necessarily represent extensive coverage of the subject:

5. Behavior of Materials at High-Strain Rates
6. Impact Measurement Devices
7. Lateral Impact-Beams and Plates
8. Miscellaneous

The general references listed at the beginning of the bibliography are a group of articles or books which cover the field of impact rather completely. No attempt has been made to duplicate the bibliographies given in these references.

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*Superscripts refer to reference numbers in the bibliography.

To improve the usefulness of the bibliography, a complete author index has been prepared along with a chronological listing of the references within a particular subject. The chronological listing is particularly helpful in giving the proper perspective to the various references.

The abstracts included are either the author's abstracts or short reviews made by this author.

To obtain current information on activities throughout the nation, an extensive trip has been made to the various centers of activity in this field. The observations made on this trip have been very enlightening and have served to give information which would not appear in the literature for some time. A report on this trip will be published in a Sandia Corporation Technical Memorandum.

The author hopes that users of the bibliography will call attention to errors or omissions.

The author would like to express appreciation to A. F. Beck who suggested this work, and Dr. S. E. Whitcomb who made many helpful suggestions.

TABLE OF CONTENTS

IMPACT PHYSICS

Reference Numbering Code

The references listed in the bibliography were given numbers within a group according to their subject with the following code being utilized.

GENERAL REFERENCES
(1-100)

1 Kolsky H
STRESS WAVES IN SOLIDS
Oxford at the Clarendon Press, 1953.
(165 references).

2 Rinehart J S and Pearson J
BEHAVIOR OF METALS UNDER IMPULSIVE LOADS
The American Society for Metals Cleveland, Ohio, 1954.
(246 references).

3 Abramson H N, Plass H J and Ripperger E A
STRESS WAVE PROPAGATION IN RODS AND BEAMS
Advances in Applied Mechanics Vol. V, 1958.
(145 references).

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BIBLIOGRAPHY ON SHOCK AND SHOCK EXCITED VIBRATIONS
Vols. I and II
The Pennsylvania State University
Engineering Research Bulletin Nos. 68 and 69.
(1583 references with abstracts).

5 Rice M H, McQueen R G and Walsh J M
COMPRESSION OF SOLIDS BY STRONG SHOCK WAVES
Solid State Physics, Advances in Research and Application Vol. 6
Academic Press, Inc. New York, 1957.

6 Davies R M
STRESS WAVES IN SOLIDS
Applied Mechanics Review Vol. 6 pp. 1-3, January 1953.
(Survey article containing 99 references).

7 Davies R M
STRESS WAVES IN SOLIDS
Surveys in Mechanics
Taylor G I Anniversary Volume
Cambridge at the University Press, 1956.
(104 references).

8 Ewing M, Jardetzky W and Press F
ELASTIC WAVES IN LAYERED MEDIA
McGraw-Hill, 1957.

9 Andersen J R and Nestler D E
SHOCK WAVE PROPAGATION IN SOLIDS
(A Survey of the Literature)
University of Pennsylvania, Project Frank, Contract NOrd-12772
ASTIA AD 39616.
(298 references annotated).

10 Goldsmith W, University of California, Berkeley
BIBLIOGRAPHY ON WAVE PROPAGATION IN SOLIDS
Private publication. (938 references).

PLASTIC WAVE PROPAGATION IN BOUNDED SOLIDS
(1000-1099)

Subtopics

Experimental technique; material behavior as deduced from wave propagation characteristics; and graphical wave propagation analysis.

PLASTIC WAVE PROPAGATION IN BOUNDED SOLIDS
(1000-1099)

Bibliography

1001 Taylor G I and Whiffin A C
THE USE OF FLAT-ENDED PROJECTILES FOR DETERMINING DYNAMIC YIELD STRESS
Proceedings of the Royal Society of London
1948, Series A, Vol. 194, p. 289.

The deformation of a flat-ended projectile, due to being fired at high velocity against a steel plate, is used as a measure of the dynamic yield stress of the projectile. In Part I the theory of the method is presented. Results of experimental tests are shown in Part II. Satisfactory results obtained for velocity of impacts from 400 to 2500 ft/sec.

1002 Johnson J E, Wood D S and Clark D S
DYNAMIC STRESS-STRAIN RELATIONS FOR ANNEALED 2S ALUMINUM UNDER COMPRESSIVE IMPACT
Journal of Applied Mechanics, Trans. ASME
1953, Vol. 75, pp. 523-529.

This paper presents the results of an experimental study of the dynamic stress-strain relations for annealed 2S Aluminum. Methods of obtaining data are presented. The technique used in analyzing the data involves the use of plastic and elastic stress-wave propagation.

Impact velocities to a maximum of about 150 fps.

1003 Von Karman T and Duwez P
THE PROPAGATION OF PLASTIC DEFORMATION IN SOLIDS
Journal of Applied Physics
1950, Vol. 21, pp. 987-994.

The stress wave caused by longitudinal impact on a cylindrical bar is analyzed for the case where impact velocity is large enough to produce plastic strain. The concept of a critical velocity is presented. An experimental investigation is performed which substantiates the theoretical presentation.

1004 Clark D S and Datwyler G
STRESS-STRAIN RELATIONS UNDER TENSION IMPACT LOADING
Proceedings ASTM
1938, Vol. 38, Part II, p. 98.

Force elongation curves are obtained for several materials for an impact velocity of 11 ft/sec. It is concluded that yield forces under dynamic conditions are higher than under static conditions.

1005 Clark D S and Duwez P E
DISCUSSION OF THE FORCES ACTING IN TENSION IMPACT TESTS OF METAL
Journal of Applied Mechanics, Trans. ASME
1948, Vol. 70, p. 243.

A method is described for measuring the forces acting on a specimen during a tension impact test. Plastic wave propagation theory is used to interpret the results obtained. Impact velocities to a maximum of 200 ft/sec. Very good article on interpretation of force-time curves obtained from such tests.

1006 Plass H J
A COMPARISON OF PLASTIC LONGITUDINAL WAVE THEORIES FOR STRAIGHT RODS
University of Texas, Defense Research Lab. N. 327, CF2009.

1007 Lee E H and Tupper S J
ANALYSIS OF PLASTIC DEFORMATION IN A STEEL CYLINDER STRIKING A RIGID TARGET
Journal of Applied Mechanics, Trans. ASME
1954, Vol. 76, p 63.

The G. I. Taylor dynamic compression test (article 1001) is used to determine the entire strain distribution for a test cylinder of nickel-chrome steel. In the interpretation of results, interest is concentrated on the plastic and elastic wave fronts which emanate from the surface of contact. The theory of the propagation of plastic waves is presented. This is a fundamental article in relation to impacts large enough to cause plastic deformation. Impact velocities to about 1500 fps.

1008 Lee E H and Wolf H
PLASTIC-WAVE PROPAGATION EFFECTS IN HIGH SPEED TESTING
Journal of Applied Mechanics, Trans. ASME
1951, Vol. 73, p. 379.

This article discusses how a material test carried out at high speed may be markedly influenced by plastic-wave

propagation effects. The range of speed is determined which permits satisfactory test interpretation without the need for detailed plastic-wave analysis.

Fundamental article on the interpretation of high speed material tests.

1009 Habib E T
A METHOD OF MAKING HIGH-SPEED COMPRESSION TESTS ON SMALL COPPER CYLINDERS
Journal of Applied Mechanics, Trans. ASME
1948, Vol. 70, p. 248
Discussion Journal of Applied Mechanics, 1949, Vol. 71, p. 98.

High-speed compression tests are performed on small copper cylinders by subjecting them to the impact of a piston fired from a pneumatic gun. Experimental techniques are discussed and results of the tests are shown as energy absorbed versus deformation. The complication due to plastic strain waves is mentioned.

Velocity of impact 25-200 fps.

1010 White M P and Griffis LeVan
THE PROPAGATION OF PLASTICITY IN UNIAXIAL COMPRESSION
Journal of Applied Mechanics, Trans. ASME
1948, Vol. 70, p. 256.
Discussion Journal of Applied Mechanics, 1949, Vol. 71, p. 219.

A theoretical investigation of the mechanism of uniaxial compression impact on elastic-plastic materials is described. It is concluded that four different modes of behavior can occur, depending on the impact velocity.

1011 Sternglass E J and Stuart D A
AN EXPERIMENTAL STUDY OF THE PROPAGATION OF TRANSIENT LONGITUDINAL DEFORMATIONS IN ELASTOPLASTIC MEDIA
Journal of Applied Mechanics, Trans. ASME
1953, Vol. 75, pp. 427-434.

An experimental study is presented which is concerned with confirming the theory of the propagation of plastic waves. It is concluded that the velocity of propagation of the wave front is that of the elastic wave which is not in agreement with theory as proposed by Von Karman and Taylor.

1012 Malvern L E
THE PROPAGATION OF LONGITUDINAL WAVES OF PLASTIC DEFORMATION IN A BAR OF MATERIAL EXHIBITING A STRAIN-RATE EFFECT
Journal of Applied Mechanics, Trans. ASME

1951, Vol. 73, pp. 203-208
Discussion Journal of Applied Mechanics, 1951, Vol. 73, pp. 428-429.

The theory of propagation of plastic longitudinal waves is extended to include the strain rate effect on the stress-strain curve.
See also 1052. Bibliography contains 30 references.

1014 White M P
ON THE IMPACT BEHAVIOR OF A MATERIAL WITH A YIELD POINT
Journal of Applied Mechanics, Trans. ASME
1949, Vol. 71, pp. 39-52
Discussion Journal of Applied Mechanics, 1949, Vol. 71, pp. 318-319.

A very complete analysis is made of impact behavior of materials with a yield point. The theory of plastic wave propagation and the combination of plastic and elastic waves is presented very clearly.

1015 White M P and Griffis LeVan
THE PERMANENT STRAIN IN A UNIFORM BAR DUE TO LONGITUDINAL IMPACT
Journal of Applied Mechanics, Trans. ASME
1947, Vol. 69, pp. A-337-343.

A method is presented for giving the final distribution of strains in a uniform bar subjected to a plastic impact. The wave propagation theories are used in the development. The presentation is very basic from the standpoint of interpretation of impact stresses and strain in cylindrical specimens.

1016 Mann H C
HIGH VELOCITY TENSION IMPACT TESTS
Proceedings ASTM
1936, Vol. 36, Part II, p. 85.

1017 Duwez P E and Clark D S
AN EXPERIMENTAL STUDY OF THE PROPAGATION OF PLASTIC DEFORMATION UNDER CONDITIONS OF LONGITUDINAL IMPACT
Proceedings ASTM
1947, Vol. 47, p. 502.

1018 Von Karman Th
ON THE PROPAGATION OF PLASTIC DEFORMATION IN SOLIDS
NDRC Report No. A-29
OSRD No. 365, 1942.

1019 Von Karman Th, Bohenblust H E and Hyers D H
THE PROPAGATION OF PLASTIC WAVES IN TENSION SPECIMENS OF FINITE LENGTH
NDRC Report No. A-103
OSRD No. 946, 1942.

1020 Campbell J D
AN INVESTIGATION OF THE PLASTIC BEHAVIOR OF METAL RODS SUBJECTED TO LONGITUDINAL IMPACT
Journal of Mechanics and Physics of Solids
1953, Vol. 1, pp. 113-123.

A dynamic stress-strain relation is obtained for an aluminum alloy. An SR-4 type strain gage is mounted on the specimen. The specimen is in the form of a long rod. Successively larger impacts are imparted to the specimen to obtain a stress-strain curve. Impact is applied to a steel rod then transmitted into the specimen. The effect of the steel rod is to increase the applied stress and also separates the flexual and longitudinal components due to differences in velocity of propagation.

1021 Bohenblust H F, Hyers D H and Charyk J V
GRAPHICAL SOLUTIONS FOR PROBLEMS OF STRAIN PROPAGATION IN TENSION
NDRC Report No. A-131
OSRD No. 1204, 1942.

1022 Von Karman Th and Duwez P E
ON THE PROPAGATION OF PLASTIC STRAINS IN SOLIDS
Presented at the Sixth International Congress for Applied Mechanics, Paris, France, September 1946.

1023 White M P and Griffis LeVan
WAVE PROPAGATION IN A UNIFORM BAR WHOSE STRESS-STRAIN CURVE IS CONCAVE UPWARD
NDRC Report No. 152
OSRD No. 1302, 1943.

1024 Lee E H
PLASTIC WAVES IN COMPRESSION
British Official Report App,
Coordinating Subcommittee No. 57, 1943.

1025 Lee E H and Tupper S J
THE ANALYSIS OF THE PLASTIC DEFORMATION IN A CYLINDER OF SHOT STEEL STRIKING A RIGID TARGET
British Official Report TRR 4/44, 1944.

1026 Taylor G I
THE PLASTIC WAVE IN A WIRE EXTENDED BY AN IMPACT LOAD
British Official Report R. C. 329, 1942.

1027 Seitz F, Lawson A W and Miller P
THE PLASTIC PROPERTIES OF METALS AT HIGH RATES OF STRAIN
NDRC Report A-41
OSRD 495, April 1942.

1028 Winslow G H and Bessey W H
HIGH SPEED COMPRESSION TESTING OF COPPER CYLINDERS AND SPHERES, II
NDRC Report A-324
OSRD Report 5039, April 1945.

1029 Wood D S, Duwez P E and Clark D S
THE INFLUENCE OF SPECIMEN DIMENSION AND SHAPE ON THE RESULTS OF TENSILE IMPACT TESTS
NDRC Report A-237
OSRD Report 3028, December 1943.

1030 Greenfield M and Habib E T
HIGH SPEED COMPRESSION TESTS ON COPPER
Journal of Applied Physics
July 1947, Vol. 18, pp. 645-650.

1031 Griffis LeVan
THE BEHAVIOR OF LONGITUDINAL STRESS WAVES NEAR DISCONTINUITIES IN BARS OF PLASTIC MATERIAL
NDRC Report A-212
OSRD 1799, September 1943.

1032 White M P
THE FORCE PRODUCED BY IMPACT OF A CYLINDRICAL BODY
NDRC Report A-157.

1033 Duwez P E, Wood D S and Clark D S
THE PROPAGATION OF PLASTIC STRAIN IN TENSION
NDRC Report No. A-99, OSRD No. 931, 1942.

1034 Bohenblust H F
ADDENDUM TO VON KARMAN's THEORY OF THE PROPAGATION OF PLASTIC DEFORMATION IN SOLIDS
NDRC Memo A-41 M
OSRD No. 664, 1942.

1035 Duwez P E, Clark D S, Wood D S and Charyk J V
THE EFFECT OF STOPPED IMPACT AND REFLECTION ON THE PROPAGATION OF PLASTIC STRAIN IN TENSION
NDRC Report No. A-108
OSRD No. 988, 1942.

1036 Bell J F
PROPAGATION OF PLASTIC WAVES IN PRE-STRESSED BARS
Technical Report No. 5, Navy Contract N6-ONR-243
Task Order III
Johns Hopkins University, June 1951.

1037 Rakhmatulin K A
PROPAGATION OF A WAVE OF UNLOADING (Russian)
Prikladnaia Matematika i Mekhanika
1945, Vol. 9, pp. 91-100.

1038 Rakhmatulin K A and Shapiro G S
ON THE PROPAGATION OF PLANE ELASTIC-PLASTIC WAVES (Russian)
Prikladnaia Matematika i Mekhanika
1948, Vol. 12, pp. 369-374.

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THE PROPAGATION OF ELASTIC VISCOUS-PLASTIC WAVES IN BARS (Russian)
Prikladnaia Matematika i Mekhanika
1948, Vol. 12, pp. 261-280.

1040 Donnell L H
LONGITUDINAL WAVE TRANSMISSION AND IMPACT
Trans. ASME, 1930, Vol. 52, pp. 153.

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ANALYSIS OF STRESS-STRAIN-TIME RELATIONS FROM THE ENGINEERING VIEWPOINT
Presented at the Second Symposium on Plasticity, Brown University, Providence, R. I.
April 1949, revised September 1951.

1042 Taylor G I
PROPAGATION OF EARTH WAVES FROM AN EXPLOSION
British Official Report R C 70, 1940.

1043 Lee E H
A BOUNDARY VALUE PROBLEM IN THE THEORY OF PLASTIC WAVE PROPAGATION
Quarterly of Applied Mathematics
1953, Vol. X-4, pp. 335-346.

1044 Brown A F C and Vincent N D G
THE RELATIONSHIP BETWEEN STRESS AND STRAIN IN THE TENSILE IMPACT TEST
Proceedings of the Institution of Mechanical Engineers, London
1941, Vol. 145, pp. 126-134.

1046 DeJuhasz K
GRAPHICAL ANALYSIS OF IMPACT OF BARS STRESSED ABOVE THE ELASTIC RANGE
Journal of the Franklin Institute
July 1949, Vol. 248, pp. 15-48 and 113-142.

This article gives a detailed explanation of the use of graphical solutions to picture and solve problems relating to the impact of bars. A bibliography on impact, consisting of 45 references, is given. Wave propagation is pictured graphically.

1047 Burr A H
LONGITUDINAL AND TORSIONAL IMPACT IN A UNIFORM BAR WITH A RIGID BODY AT ONE END
Journal of Applied Mechanics, Trans. ASME
1950, Vol. 72, pp. 209-217
Discussion Journal of Applied Mechanics
1950, Vol. 72, pp. 462-465.

1048 Riparbelli C
ON THE RELATION AMONG STRESS, STRAIN, AND STRAIN RATE IN COPPER WIRES SUBMITTED TO LONGITUDINAL IMPACT
Proceedings Society for Experimental Stress Analysis
1956, Vol. XIV, No. 1, pp. 55-70.

A series of exploratory tests of tensile impact on copper wires is presented to show that the elastic component of a stress wave moves at a constant velocity regardless of the amount of plastic deformation. Method consists of dropping weight on copper wire. Bright tin spots on wire are photographed with high-speed photography to observe motion of the stress waves.

1049 Alter B E K and Curtis C W
EFFECT OF STRAIN RATE ON THE PROPAGATION OF A PLASTIC PULSE ALONG A LEAD BAR
Journal of Applied Physics
1956, Vol. 27, pp. 1079-1085.

A very thorough article on the effect of strain rate on the velocity of propagation of a plastic wave in a bar. Tests were carried out to determine how pulses of plastic deformation disperse during propagation along a lead bar. The theory of rate of propagation is reviewed and experimental results are presented. Article contains a list of 20 references.

1050 Wood D S
ON LONGITUDINAL PLANE WAVES OF ELASTIC-PLASTIC STRAIN IN SOLIDS
Journal of Applied Mechanics, Trans. ASME
1952, Vol. 74, pp. 521-525.

1051 Taylor G I
THE TESTING OF MATERIALS AT HIGH RATES OF LOADING
Journal of the Institution of Civil Engineers
1946, Vol. 26, pp. 486-519.

1052 Malvern L E
PLASTIC WAVE PROPAGATION IN A BAR OF MATERIAL EXHIBITING A STRAIN RATE EFFECT
Quarterly of Applied Mathematics
1951, Vol. 8, pp. 405-411.

1053 Campbell J D and Duby J
THE YIELD BEHAVIOR OF MILD STEEL IN DYNAMIC COMPRESSION
Proceedings Royal Society of London
1956, Series A, Vol. 236, pp. 24-40.

Experiments are described in which a mild steel specimen is subjected to a compressive impact load. Stress-time curves are obtained and analyzed. Micrographs of specimens after yielding are shown to show the metallurgical mechanism of yielding.

1054 Kolsky H
AN INVESTIGATION OF THE MECHANICAL PROPERTIES OF MATERIALS AT VERY HIGH RATES OF LOADING
Proceedings Physical Society of London
1949, Vol. 62, p. 676.

1057 Lee E H
WAVE PROPAGATION IN ANELASTIC MATERIALS, DEFORMATION AND FLOW OF SOLIDS
Colloquium, Madrid, 26-30 September 1955
Berlin, Springer Verlag, 1956
Also Office of Naval Research Contract Nonr-562(10)
NR-064-406, Brown University, Technical Report No. 5
December 1955.

1058 Ogibalov P M and Loginova M A
ON THE DEPENDENCE OF THE STRAINS IN A RAPID DEFORMATION UNDER IMPULSIVE LOADING BEYOND THE YIELD POINT (Russian)
Vestnik, Moskov University No. 5, pp. 39-58, 1948.

1059 Lensky V S
ON THE ELASTOPLASTIC IMPACT OF A ROD AGAINST A RIGID OBSTACLE (Russian)
Prikladnaia Matematika i Mekhanika
March/April 1949, Vol. 13, pp. 165-170.

1060 Lebedev N F
SECONDARY ELASTOPLASTIC WAVE (Russian)
Prikladnaia Matematika i Mekhanika
March/April 1954, Vol. 18, pp. 167-180.

1061 Campbell W R
DETERMINATION OF DYNAMIC STRESS-STRAIN CURVES FROM STRAIN WAVES IN LONG BARS
Proceedings Society for Experimental Stress Analysis
1952, Vol. 10, No. 1, pp. 113-124.

An exploratory experimental program is conducted to determine the feasibility of using a tangent modulus method to determine dynamic stress-strain curves. Analytical procedure is outlined and experimental results are presented. Measurements made with SR-4 type strain gages.

1062 Zener C and Hollomon J H
EFFECT OF STRAIN RATE UPON PLASTIC FLOW OF STEEL
Journal of Applied Physics
1944, Vol. 15, pp. 22-32.

1063 Bell J F
THEORETICAL AND EXPERIMENTAL STUDIES OF PLASTIC WAVE PROPAGATION IN LONGITUDINAL RODS SUBJECT TO IMPACT
Johns Hopkins University, Institute for Cooperative Research
Contract No. DA-36-034-ORD-2366, 1956.

A new method employing diffraction gratings of very short length will be utilized to study propagated plastic wave fronts of large magnitude. Unloading waves, reflected waves from fixed and free ends. Dynamic determination of Poisson's ratio.

1064 Rubin R J
PROPAGATION OF LONGITUDINAL DEFORMATION WAVES IN A PRESTRESSED ROD OF MATERIAL EXHIBITING A STRAIN-RATE EFFECT
Journal of Applied Physics
1954, Vol. 25, pp. 528-536.

The longitudinal propagation of stresses above the yield stress in a material exhibiting a strain-rate effect is studied analytically. Mathematical expressions are developed which describe the wave propagation. The system analyzed is a semi-infinite rod subjected to end impact.

This article is referred to by many investigators and several extensive experiments are being conducted to verify this theory.

1065 Campbell J D
THE YIELD OF MILD STEEL UNDER IMPACT LOADING
Journal of Mechanics and Physics of Solids
1954, Vol. 3, pp. 54-62.

In an extension of work reported in article 1020 the dynamic stress-strain curves of mild steel are obtained. The apparatus is adapted so that the steel rod which transmits the stress to the specimen is larger than the specimen. This increases the stress transmitted into the specimen. The strain gage is attached to the specimen.

1066 Campbell J D and Maiden C J
THE EFFECT OF IMPACT LOADING ON THE STATIC YIELD STRENGTH OF A MEDIUM CARBON STEEL
Journal of Mechanics and Physics of Solids
1957, Vol. 6, pp. 53-61.

Although the results of this investigation are not of particular interest the experimental technique is interesting. A similar test setup is used as in articles 1020, 1065. Stress magnitude is amplified by transmitting the impact through steel rods of two cross-section changes. This amplifies the stress about two times. Strain gages are attached to the anvil bar.

1067 Riparbelli C
A PARADOX IN THE THEORY OF IMPACT
Journal of the Aeronautical Sciences
1954, Vol. 21, pp. 429-430.

1068 Gilhamet J and Goldsmith W (Translators)
PROPAGATION OF PLASTIC STRAIN
Translation of five articles from Russian and French

1. On Explosions in a Compressible Plastic Medium
   Altschuler V

2. Concerning a Dynamic Problem of Thermoelasticity
   Danilovskaya I

3. Elasto-Plastic Waves of Loading
   Bakhshian R A

4. The Propagation of Cylindrical Waves of Plastic Deformation (Torsional Impact)
   Rakhmatulin Kh A

5. The Propagation of Spherical Waves in an Elasto-Plastic Medium
Luntz Ya L

University of California, Institute of Engineering Research, July 1953.

PLASTIC WAVE PROPAGATION

Chronological Listing

Year	Reference number(s)						
1958							
1957	1066						
1956	1048	1049	1053	1063			
1955	1057						
1954	1007	1060	1064	1067	1065		
1953	1002	1011	1020	1043	1068		
1952	1050	1061					
1951	1008	1012	1036	1052			
1950	1003	1047					
1949	1014	1041	1046	1054	1059		
1948	1001	1005	1009	1010	1038	1039	1058
1947	1015	1017	1030				
1946	1022	1051					
1945	1028	1037					
1944	1025	1062					
1943	1023	1024	1029	1031			
1942	1018	1019	1021	1027	1033	1034	1035
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1940	1042						
1939							
1938	1004						
1937							
1936	1016						
1930	1040						

BEHAVIOR OF METALS UNDER EXPLOSIVE CONDITIONS (1100-1199)

Subtopics

Equations of states of solids; experimental techniques; free surface velocity determinations; scabbing (analysis and experimental) and fracture.

BEHAVIOR OF METALS UNDER EXPLOSIVE CONDITIONS
(1100-1199)

Bibliography

1101 Rinehart J S and Pearson J
ENGRAVEMENT OF TRANSIENT STRESS WAVE PARTICLE VELOCITIES
Journal of Applied Physics
1953, Vol. 24, pp 462-469.

A simple and unique technique is described for determining the particle velocity of a material subjected to high-speed loading. The force is applied to a plate that has a pellet attached on the opposite side. The propagation of the wave through the plate and pellet causes the pellet to indent the surface of the plate. Average particle velocity can be determined by measuring the depth of penetration.

1102 Shreffler R G and Deal W E
FREE SURFACE PROPERTIES OF EXPLOSIVE-DRIVEN METAL PLATES
Journal of Applied Physics
1953, Vol. 24, pp. 44-48.

A photographic technique for study of metal-free surfaces under acceleration by high explosives is presented. Methods for reducing the data from the photographic record are described. Specific results using brass plates driven by explosives are cited. (Author's abstract)

1103 Allen W A
FREE SURFACE MOTION INDUCED BY SHOCK WAVES IN STEEL
Journal of Applied Physics
1953, Vol. 24, pp. 1180-1185.

Free surface motion is studied by photographing the motion of the image of point light sources on a highly polished steel surface. Plate is forced by the detonation of explosives. Results are analyzed.

For details of experimental technique, see article 1051.

1104 Rinehart J S
SOME QUANTITATIVE DATA BEARING ON THE SCABBING OF METALS UNDER EXPLOSIVE ATTACK
Journal of Applied Physics
1951, Vol. 22, pp. 555-560.

The phenomenon of scabbing is stated to be dependent on the stress distribution within a wave and a critical normal stress that is a characteristic of the material. This paper presents the results of a modified Hopkinson pressure bar experiment in which results of stress versus time and critical velocity were obtained.

1105 Allen W A and McCrary C L
EXPERIMENTAL TECHNIQUE USED TO MEASURE TRANSIENT WAVES THROUGH SOLIDS
Review of Scientific Instruments
1953, Vol. 24, pp. 165-171.

1106 Walsh J M and Christian R H
EQUATION OF STATE OF METALS FROM SHOCK WAVE MEASUREMENTS
Physicial Review
1955, Vol. 97, pp. 1544-1556.

Pressure magnitudes of from 150 to 500 kilobars were obtained from metals with high explosives. Free surface velocities were determined by photographing the movement of shock waves in air or argon due to the pressure wave in the material. Results are analyzed and techniques are described.

1107 Allen W A and McCrary C L
TRANSIENT WAVES THROUGH STEEL PRODUCED BY IMPULSIVE LOADING
Paper presented at meeting of American Physical Society
Berkeley, California, December 27-29, 1951
Abstract in Physical Review, 1952, Vol. 85, p. 769.

The transient behavior of a thick circular plate deforming under explosive attack has been investigated. An experimental technique, based upon the principle of the optical lever has been used to measure surface oscillations as small as 10μ in amplitude. Measured particle velocities determined by this method indicate the presence of elastic and plastic waves.

1108 Rinehart J S and Pearson J
SOME TENSILE FRACTURES GENERATED IN METALS BY IMPULSIVE COMPRESSIONAL LOADING
Paper presented at meeting of American Physical Society
Berkeley, California, December 27-29, 1951
Abstract in Physical Review, Vol. 85, p. 768.

One aspect of the part that high intensity stress waves play in the fracturing of metal cylinders subjected to internal explosive loading has been studied. It has been found that tensile type fractures will result from the interference of reflected tensile stress waves whenever the resulting tensile stress exceeds the critical normal fracture stress of the material. Stress wave velocities have been measured for low-carbon steel, brass, copper, lead and aluminum alloys from the geometry of fracture. These velocities are in reasonable agreement with accepted values for the velocities of dilatational waves in these metals.

1109 Rinehart J S
SCABBING OF METALS UNDER EXPLOSIVE ATTACK, MULTIPLE SCABBING
Journal of Applied Physics
1952, Vol. 23, pp. 1229-1233.

The mechanism of multiple scabbing is explained in terms of stress propagation theory. Experimental results are shown which verify the theory. Particle velocities are determined by the use of pellets in a hole drilled on the back of the plate.

1110 Rinehart J S
SOME EXPERIMENTAL INDICATIONS OF THE STRESSES PRODUCED IN A BODY BY AN EXPLODING CHARGE
Journal of Applied Physics
1951, Vol. 22, pp. 1178-1181.

The effects of detonating explosive charges on the surface of heavy steel plates is discussed. The mechanism of failure is discussed and stress distribution is determined by conducting a hardness survey after the plate is sectioned. Experimental techniques are not discussed.

1111 Pack D C, Evans W M and James H J
THE PROPAGATION OF SHOCK WAVES IN STEEL AND LEAD
Proceedings of the Physical Society, London
1948, Vol. 60, pp. 1-8.

An experimental investigation is presented in which transit times for the passage of a shock wave through plates are measured. Wave is instigated by the detonation of explosive. Lead and steel plates are used. Time measured by making and breaking electrical contacts.

1112 Rinehart J S
WORK HARDENING OF MILD STEEL BY EXPLOSIVE ATTACK
Journal of Applied Physics
1951, Vol. 22, pp. 1086-1087.

1113 Wood R W
OPTICAL AND PHYSICAL EFFECTS OF HIGH EXPLOSIVES
Proceedings Royal Society, London.
1936, Series A, Vol. 157, pp. 249-261.

The deformation of the copper cap on an explosive detonator is studied to gain information about the mechanism of detonation. A spectroscopic investigation of the exploding materials is also made.

1114 Broberg K B
SHOCK WAVES IN ELASTIC AND ELASTIC-PLASTIC MEDIA
Kungl. Fortifikations for valtningen Befästningsbyran
Rappart 109-12, 141 pp. 1956. Library of Congress P. B. 126210.

Report gives interesting review of experiments on the propagation of elastic, plastic and shock waves produced by impact and by the detonation of explosive charges. The theory of wave propagation is discussed and the propagation of spherically divergent stress-waves is treated in detail. Tables of numerical values of dynamic stress-strain results for metals and other solids are presented and the fractures produced by the reflection of intense stress waves at the free boundaries of a specimen, are described and discussed. The bibliography contains 71 references in the field, most of which are recent. (Abstract as given in Applied Mechanics Review).

1115 Broberg K B
STUDIES ON SCABBING OF SOLIDS UNDER EXPLOSIVE ATTACK
Journal of Applied Mechanics, Trans. ASME
1955, Vol. 77, pp. 317-323.

The mechanism of the scabbing phenomenon is discussed both theoretically and experimentally. Experimental method used to determine pressure-time relation on face of plate where detonation occurs, is a modified pressure bar. Plane scabbings are obtained by inserting cylinders in hole in plate.

1116 Kumar S and Davids N
ELASTIC-PLASTIC ANALYSIS OF SCABBING OF MATERIALS
Journal of the Franklin Institute
May 1958, Vol. 265, pp. 371-383.

The graphical method is used to analyze stress propagation. Stress states are analyzed which can cause scabbing. No experimental work is presented.

1117 Kumar S and Davids N
MULTIPLE SCABBING IN MATERIALS
Journal of the Franklin Institute
1957, Vol. 263, p. 295.

1118 Goldsmith W and Allen W A
GRAPHICAL REPRESENTATION OF THE SPHERICAL PROPAGATION OF EXPLOSIVE PULSES IN ELASTIC MEDIA
Journal of the Acoustical Society of America
1955, Vol. 27, pp. 47-55.

Analytic expressions of displacements, velocities and stresses as a function of location and time, as solved with the use of an IBM machine, are presented in pictorial form. Presentation is applicable to spherical divergent waves in homogeneous, isotropic, elastic media of infinite extent under the waves generated by an explosion on one face of the medium. Graphs permit a rapid evaluation of the nature of the disturbance.

1119 PLASTIC DEFORMATION AND FORMATION OF CRACKS BY DETONATING CHARGES (Swedish)
Ingen. Vetensk. Akad. Tidsk. Tekn. Forsk.
1955, Vol. 26, pp. 16-25.

Author discusses the plastic deformation and some of the fractures which occur when an explosive charge is detonated in intimate contact with, or a high-velocity fragment strikes a solid body. Several specific examples that have not been heretofore reported are described. Each example is accompanied by a brief description of the other investigations that are most likely to lead to an understanding of what has taken place in each case.

1120 Pearson J and Rinehart J S
SURFACE MOTION ASSOCIATED WITH OBLIQUELY INCIDENT ELASTIC WAVES
Journal of the Acoustical Society of America
1953, Vol. 25, pp. 217-219.

Well-known laws which govern the reflection of elastic waves that strike free surfaces obliquely, are used to deduce particle motion at the free surface of a body__

The data are expected to be of value in the solution of problems connected with impulsively loaded bodies such as metal-explosive systems. (Excerpt from author's summary).

1121 Pearson J and Rinehart J S
COMPUTATION RELATING TO REFLECTION OF PLANE ELASTIC WAVES STRIKING FREE SURFACES OBLIQUELY
13 August 1952, NOTS TM No. 931.

1122 Allen W
ELASTIC DESCRIPTION OF A HIGH-AMPLITUDE SPHERICAL PULSE IN STEEL
21 April 1953, NOTS TM No. 994.

1123 Huth J H and Cole J D
A THEORETICAL TREATMENT OF SPALLING
Rand R M - 1181.

1124 Evans W M and Taylor G I
DEFORMATION AND FRACTURES PRODUCED BY INTENSE STRESS PULSES IN STEEL
Research, 1952, Vol. 5, pp. 502-509.

The mechanism of plastic deformation and fracture due to high explosives is investigated by studying the fractures produced. Specimens are sectioned and etched. Metallurgraphic photomicrographs are made to study the change in crystalline structure. Article is well illustrated with typical fractures.

1125 Kolsky H and Shearman A C
INVESTIGATION OF FRACTURES PRODUCED BY TRANSIENT STRESS WAVES
Research, 1949, Vol. 2, pp. 384-389.

The mechanism of fracture due to detonation of explosives is studied by observing the fractures of bodies of various shapes. Plastic bodies are used. Large plates, small plates, cylinders, and cones are investigated. Various fractures are well illustrated.

1126 Kochler J S and Seitz F
THE STRESS WAVES PRODUCED IN A PLATE BY A PLANE PRESSURE PULSE
1944, OSRD Report No. 3230.

1127 Rinehart J S and Pearson J
CONICAL SURFACES OF FRACTURE PRODUCED BY ASYMMETRICAL IMPULSIVE LOADING
Journal of Applied Physics
1952, Vol. 23, pp. 685-687.

The conical surface of fracture of an explosively loaded thick wall cylinder is analyzed from the

standpoint of stress wave propagation. It is shown that the angle of failure is a function of the velocity of propagation of the wave. Experimental results are shown which tend to verify the explanation.

1128 Pearson J and Rinehart J S
DEFORMATION AND FRACTURING OF THICK-WALLED STEEL CYLINDERS UNDER EXPLOSIVE ATTACK
Journal of Applied Physics
1952, Vol. 23, pp. 434-441.

This article discusses the deformation and fracturing of thick-walled cylinders due to internal explosives. The presentation is primarily focused on describing the mechanism of failure that occurs under these circumstances. Stress wave propagation and behavior of the material are not emphasized in the presentation.

1129 Starr L and Savitt J
SPALLING PRODUCED BY DETONATION OF EXPLOSIVE IN VERY HEAVY WALLED METAL TUBES
Physical Review
1952, Vol. 86, pp. 600.

1130 Rinehart J S
HARDNESS PLATEAUS AND TWINNING IN EXPLOSIVELY LOADED MILD STEEL
Journal of Applied Physics
1954, Vol. 25, p. 778.

1131 Mallory H D
PROPAGATION OF SHOCK WAVES IN ALUMINUM
Journal of Applied Physics
1955, Vol. 26, pp. 555-559.

The velocity of shock waves in aluminum and the associated translational motions, produced by metal-metal impact, have been determined by an electrical contact technique. The results obtained have been used to evaluate an equation of state for the metal. (Author's abstract)

1132 Rinehart J S
SOME OBSERVATIONS ON HIGH SPEED IMPACT
U. S. Naval Ordnance Test Station
Technical Memorandum RRB-50
19 October 1949.

1133 Rinehart J S
THE BEHAVIOR OF METAL UNDER HIGH AND RAPIDLY APPLIED STRESSES OF SHORT DURATION
U. S. Naval Ordnance Report No. 1183
27 September 1949.

A number of interesting effects produced as the result of detonating explosive charges in intimate contact with metal plates, rods, and tubes are described. The principal observable effects are (1) fracturing of the metal caused by a tensional stress produced as the result of the reflection of a high compressional stress wave at a free boundary, (2) the fracturing of the metal caused by high stress concentration, and (3) permanent straining of the metal. (Author's abstract)

1134 Scardin H
MEASUREMENTS OF SPHERICAL SHOCK WAVES
Communications on Pure and Applied Mathematics
1954, Vol. 7, pp. 223-243.

Although this article is primarily concerned with shock waves produced by explosives in air, it develops the pressure versus time data on explosives. Experimental data is shown which verify the experimental results. Photographs shown from multiple-spark camera, streak camera, condenser-microphone, kerr-cell photography, x-ray-photography.

1135 Walsh J M, Rice M H, McQueen R G and Yarger F L
SHOCK WAVE COMPRESSIONS OF TWENTY-SEVEN METALS
EQUATIONS OF STATE OF METALS
Physical Review
1957, Vol. 108, Part 1, pp. 196-216.

An explosive system is used to drive a strong shock wave into a plate of 24 ST aluminum. This shock wave propagates through the 24 ST aluminum into small test specimens which are in contact with the front surface of the plate. A photographic technique is used to measure velocities associated with the 24 ST aluminum shock wave and with the shock wave in each specimen. Resulting pressure-compression curves are given for 27 metals. pressure interval 150 to 400 kilobars. Very detailed information on the various metals behavior is given. (Author's abstract)

1136 Bancroft D, Peterson E L and Minshall S
Journal of Applied Physics
1956, Vol. 27, pp. 291-298.

This article investigates the propagation of compressive waves generated by high explosive in Armco iron. The pin technique is used to obtain free surface velocities. The presentation is given to investigate whether three stable shocks are propagated. Problem of wave propagation and reflection is well discussed.

1138 Drummond W E
EXPLOSIVE-INDUCED SHOCK WAVES, PART II OBLIQUE SHOCK WAVES
Journal of Applied Physics
1958, Vol. 29, pp. 167-170.

The explosive production of oblique shock waves in solids is analyzed in the approximation that third and higher order terms in the shock strength can be neglected, and a procedure is developed for calculating the attenuation of the shocks. Application is made to the problem of determining the equation of state of the burned explosive gas. See also 1139. (Author's abstract)

1139 Drummond W E
EXPLOSIVE INDUCED SHOCK WAVES, PART I, PLANE SHOCK WAVES
Journal of Applied Physics
1957, Vol. 28, pp. 1437-1441.

1140 Deal W E
SHOCK HUGONIOT OF AIR
Journal of Applied Physics
1957, Vol. 28, pp. 782-784.

Experiments are described in which an explosive driven plate set up a strong shock in air in contact with the plate. Free surface velocity and air shock velocity are measured by means of a high-speed framing camera which views the plate in profile.

Experimental results are shown for pressures up to 200 bars. A 24 St Dural plate is used.

1141 Allen W A and Goldsmith W
SPALL EFFECTS PRODUCED BY A CYLINDRICAL AND A SPHERICAL CHARGE OF HIGH EXPLOSIVE
Journal of Applied Physics
1954, Vol. 25, pp. 813-814.

A letter to the editor discusses the feasibility of using a spherical charge in replacement for a cylindrical charge in determining spall effects on the free surface of a plate.

1142 Becker H
ON SHOCK PROPAGATION IN BRASS
Journal of Applied Physics
1954, Vol. 25, pp. 1066-1067.

1143 Savitt J, Stresau R H and Starr L E
COMPRESSION WAVE VELOCITY EXPERIMENTS WITH COPPER
Journal of Applied Physics
1954, Vol. 25, pp. 1307-1310.

The velocity of compression waves in copper is investigated by detonation of explosives inside cylinders. The angle of failure of the end of the cylinder is taken as proportional to the wave velocity. Theory is explained and results are compared to article 1127.

1144 Mallory H D
ON THE EXISTENCE OF A BINARY REACTION ZONE AT A METAL-EXPLOSIVE BOUNDARY DURING DETONATION
U. S. Naval Ordnance Laboratory 1954
Library of Congress P. B. 122054.

This report is a summary of recent progress made in the interpretation of pin-point data. The pin technique has been used to measure the free surface velocity of aluminum targets struck by a plane detonation wave from crystalline TNT at a loading density of 0.624 g/cc. (Author's abstract)

1145 Rinehart J S
DEFORMATION OF AN EXPLOSIVELY LOADED ALUMINUM SINGLE CRYSTAL
Journal of Applied Physics
1955, Vol. 26, pp. 1315-1318.

A hollow cylindrical single crystal of pure aluminum was deformed by detonating an explosive charge that had been placed axially within the crystal. The approximate strain rate achieved was 10^5 sec^{-1}. The object of the test was to relate the pattern of deformation to the stresses set up by the explosive and the crystallographic axes of the crystal. The reaction of the cylinder was markedly different from the reaction which would be exhibited by a similarly shaped cylinder of polycrystalline material. The deformation was nonuniform with both the fracturing and the plastic flow exhibiting a twofold symmetry that could be unambiguously related to the orientation of stress with respect to the crystallographic axes and their associated slip systems. (Author' s abstract)

1146 Goranson R W, Bancroft D, Burton B L, Blechar T, Houston E E, Gittings E F, and Landeen S A
DYNAMIC DETERMINATION OF THE COMPRESSIBILITY OF METALS
Journal of Applied Physics
1955, Vol. 26, pp. 1472-1479.

Equation of state data for Duralumin in the pressure range from 0.1 to 0.3 megabar have been determined dynamically by measuring shock and free surface velocity electrically in a plate of 24 ST Duralumin that has been stressed by a high explosive detonation. A theory is presented which allows comparison with data obtained by other experimenters, and which yields the relationship

between pressure and compression either at constant entropy or constant temperature. The empirical form chosen for the equation of state ($p = a\mu + \beta\mu^2$) expresses the pressure as a quadratic function of the compression. Experimental techniques are described in detail. Five points are given for the equation of state of Duralumin in the pressure range from approximately 0.15 megabar to 0.33 megabars. Some data are also presented for cadmium and steel. (Authors' abstract)

1147 Pearson J and Rinehart J S
APPLICATION OF THE ENGRAVEMENT METHOD TO THE STUDY OF PARTICLE VELOCITY DISTRIBUTION IN EXPLOSIVELY LOADED CYLINDERS
Journal of Applied Physics
1955, Vol 26, pp. 1431-1435.

Application of the engravement method to the study of particle velocity distribution in the wall of a thick-walled metal cylinder internally loaded with an explosive charge is described. Tests were conducted with this method on modified cylinders of annealed low-carbon steel and of brass. Even though each of the modified cylinders broke into a number of fragments, the engravements were well enough preserved to furnish considerable data. Many measurements were obtained from each cylinder by using a large number of pellets of several thicknesses. Particle velocity data were obtained to within 7/16 inch from the metal explosive interface. Temporal particle velocity distribution curves are presented for each of the cylinders. (Author's abstract)

1148 Minshall S
PROPERTIES OF ELASTIC AND PLASTIC WAVES DETERMINED BY PIN CONTACTORS AND CRYSTALS
Journal of Applied Physics
1955, Vol. 26, pp. 463-469.

Experimental techniques are described by which one can observe the separation of a shock wave in a metal into an elastic wave and a slower plastic wave. The plastic-wave velocity was about 15 percent less in steel and 10 percent less in tungsten than the elastic-wave velocity, at pressures imparted by Composition B explosive. Elastic-wave velocities were the same, within experimental error, as the measured sound velocities. The pressure in the elastic wave in SAE 1020 steel, deduced from the material and wave velocities, is independent of the plastic-wave pressure within experimental accuracy, and is about 12 kilobars. SAE 1040 steel, however, does not exhibit a single characteristic elastic-wave pressure. The pressure initially is about 6 kilobars and increases to about 12 kilobars before the arrival of the plastic wave. (Author's abstract)

1149 Allen W A, Mapes J M and Mayfield E B
SHOCK WAVES IN AIR PRODUCED BY ELASTIC AND PLASTIC WAVES IN A PLATE
Journal of Applied Physics
1955, Vol. 26, pp. 125-126.

Letter to the editor describing shock waves in air produced by free surface velocity of plate. Shadow graphs are shown of these waves. Two shock waves shown for brass but only one wave for copper. Steel and lead also reported. No numerical results presented.

1150 Savitt J
A NOTE ON SHOCK PROPAGATION IN BRASS
Journal of Applied Physics
1953, Vol. 24, p. 1335.

A theoretical description is given on the propagation of longitudinal waves through a body of large lateral extent. (Plates) Combination of elastic and plastic stresses is investigated.

1151 Murgai M P
APPLICATION OF THE HERTZ THEORY OF IMPACT TO EXPLOSION PHENOMENON
Journal of Chemical Physics
1954, Vol. 22.2, pp. 1687-1689.

1152 Singh Sampooran
SPATIAL DISTRIBUTION OF FRAGMENTS OF EXPLOSIVELY LOADED THIN-WALLED STEEL CYLINDERS
Proceedings Physical Society
1956, Vol. 69-B, pp. 1089-1094.

1153 Allen W A and Goldsmith W
ELASTIC DESCRIPTION OF A HIGH-AMPLITUDE SPHERICAL PULSE IN STEEL
Journal of Applied Physics
1955, Vol. 26, pp. 69-74.

Extensive calculations have been performed with an electronic calculator to evaluate a problem in elasticity that simulates the effect of a cylindrical charge of high explosive detonated in intimate contact with a steel plate. The general method of calculation has been described in detail. Although elastic theory has been extrapolated into a regime where it is known not to apply, insight of a valuable general nature has been obtained on the nature of the negative component of the pulse. (Author's abstract)

1155 Kumar S and Davids N
BASIC THEORY OF SCABBING-ELASTO-PLASTIC WAVE PROPAGATION
Interim Technical Report No. 10, Pennsylvania State University.

Semi-graphical approaches to the propagation of stress pulses in bars created by impacts is presented. This report consists of two main parts, viz., "Stress Jump Approach" and the "Strain Contour Approach." In the first part, after a brief discussion and development of the theory of plastic wave propagation, solutions of a number of problems with various boundary conditions for rectangular and triangular pulses of both long and short duration, are presented. An idealized stress-strain diagram for 14 ST-4 Aluminum alloy obtained in our laboratory has been used for most of the above cases. In the second part, first the theory of contour propagation in the X-T plane is developed and a set of rules that govern their geometrical patterns are presented. Then solutions are provided for most cases of reflections and interactions of the strain and velocity contours that are considered necessary for solving any given problem. (Authors' abstract)

1156 Dewey J, Breidenbach H I and Gehring J W
SOME OBSERVATIONS OF ELASTIC PROPERTIES OF SOLIDS UNDER EXPLOSIVE LOADING
Ballistic Research Laboratories, Report No. 931.

The strains and shock fronts in a magnesium alloy subjected to a contact detonation have been determined from flash radiographs. From these the stresses and stress-strain ratios for the compressional and shearing strains at the shock fronts have been computed, using finite strain theory. The compressional stress-strain ratio exceeds the infinitesimal and increases rapidly with strain. The shearing stress-strain ratio is considerably lower than the infinitesimal and about that predicted from Murnaghan's second order theory, $\mu - p$. Much less complete observations on plate glass and Catalin 61-893 are reported and reduced. Observations on heavier materials give subsonic shock velocities under very high stresses. In all materials except glass the compression front is markedly curved, indicating a rapid decay of shock strength. (Authors' abstract)

1157 Kumar S and Davids N
MULTIPLE SCABBING IN MATERIALS
Interim Technical Report No. 4, OOR Project TB2 -0001 (1253), Pennsylvania State University.

This report discusses first, scabbing and multiple scabbing from a phenomenological point of view, then past experiments on scabbing with critical comments. It then suggests new types of experiments and the use of an

inverse approach which could yield information on pulse shapes and some of the dynamic properties of the material. The relationships among these quantities have been determined graphically. (Authors' abstract)

1158 Davids N and Kumar S
THE BASIC THEORY OF SCABBING IN MATERIALS WITH TWO SOLIDS IN CONTACT, PART I, ELASTIC THEORY
Interim Technical Report No. 1, OOR Project TB2-0001 (1253), Pennsylvania State University.

Basic relationships for scab formation in a solid are developed from the point of view of elastic materials. Relationships giving the thickness of scabs are obtained for semi-infinite plates and thin rods on the basis of normally-incident pressure pulses of arbitrary form. The effect of a backing medium has been expressed in terms of impedance matching relations between the two media, and these used to determine quantitatively the reduction in stress. Criteria for required thicknesses are developed on the basis of momentum considerations. A preliminary treatment is included for spherically-diverging waves arising from a point explosion in a semi-infinite medium. Some available data are made use of in a discussion for the purpose of evaluating time constants of typical pressure pulses used in the report. (Authors' abstract)

1159 Davids N
STRESS WAVES OF PENETRATION IN PLATES
Interim Technical Report No. 12, OOR Project No. TB2-0001 (1253) Pennsylvania State University.

Scabbing effects in plates may be analyzed theoretically by assuming elastic stress-waves excited periodically at a point-source on its boundary. The usual classical results are inaccurate since, first, the damaging wave is the one penetrating through the plate rather than propagating along it, and second, the dimensions of the plate in practical applications are just of the order of a wavelength. A more precise boundary-value problem is worked out and resulting axial stress-wave distributions for aluminum plates are given. (Author's abstract)

1160 Kumar S
SCABBING IN BARS AND PLATES - FURTHER STUDIES
Interim Technical Report No. 13, OOR Project TB2-0001(1253) Pennsylvania State University.

Scabbing, a fracture phenomenon in materials, due to stress reversal of strong dynamic loads, is first discussed here from a phenomenological point of view. Then an elastic analysis for determining scab lengths both in bars and plates under plane stress and plane strain is presented. As a further refinement, after explaining briefly and applying the basic theory of

elastoplastic wave propagation in solids, a study is made of scabbing possibilities in bars by semi-graphical methods, and also the basis for the elasto-plastic analysis of scabbing in plates. Implications of both the elastic and elastoplastic analyses are compared. Idealized stress-strain relations for 14ST-4 Aluminum, obtained in our laboratory, have been used. (Author's abstract)

1161 Duvall G E
PRESSURE-VOLUME RELATIONS IN SOLIDS
American Journal of Physics
1958, Vol. 26, pp. 235-238.

An equation of state of the form $P(V) = f(V) + Tg(V)$, which is useful for condensed matter, is proposed for the illustration of thermodynamic principles. Pressure-volume relations for adiabatic and shock compressions are derived with the assumption that specific heat at constant volume is independent of temperature. These derived relations are illustrated for a "Murnaghan" equation of state, and constants of this equation for several metals are tabulated. (Author's abstract)

1162 Duvall G E and Zwolinski B J
ENTROPIC EQUATIONS OF STATE AND THEIR APPLICATION TO SHOCK WAVE PHENOMENON IN SOLIDS
Journal of the Acoustical Society of America
1955, Vol. 27, pp. 1054-1058.

1163 Drummond W E
COMMENTS ON THE CUTTING OF METAL PLATES WITH HIGH EXPLOSIVE CHARGES
Journal of Applied Mechanics, Trans. ASME,
1958, Vol. 80, pp. 184-188.

1164 Kumar S
SCABBING AND PULSE PROPAGATION IN MATERIALS
The Pennsylvania State University Interim Technical Report No. 14
OOR Research Project No. TB2-0001 (1253).

1165 Davids N and Kumar S
STRESS WAVES AND SCABBING IN MATERIALS
OOR Technical Memorandum 58-1, May 1958
(73 references).

1166 Katz S, Curran D R and Doran D G
HUGONIOT EQUATION OF STATE OF ALUMINUM AND STEEL FROM OBLIQUE SHOCK MEASUREMENT
Stanford Research Institute, Poulter Laboratories, Lab. Technical Report 018-57, December 1957.

A new method for determining the Hugoniot equation of state of solids has been developed. This method uses an oblique shock in a wedge-shaped specimen, cut so that the oblique shock is incident at an angle close to normal over the wedge face. The oblique shock is produced by a slab of explosive, lying on top of the wedge and line-initiated, providing essentially a two-dimensional shock. Simultaneous measurement of shock and free-surface velocities down the wedge face provides the data for calculation of the Hugoniot pressure and density over a wide range on a single shot. In aluminum a pressure range exceeding 2:1 may be observed on a single shot. (Authors' Summary)

1167 Al'tshuler L V, Krupnikov K K, Ledenev B N, Zhuchikhin V I and Brazhnik M I
THE DYNAMIC COMPRESSIBILITY AND THE EQUATION OF STATE FOR IRON AT HIGH PRESSURES
Zhur. Eksper. i Teoret. Fiz. 34:874-85, No. 4, April 1958.

The paper describes two methods for measuring the dynamic compressibility of substances. These methods are based on determining the kinematic parameters of shock waves (propagation velocity and the mass velocity of the material behind the wave front). Using these methods in the pressure range from 4×10^5 to 5×10^6 atm., the adiabatic curves are obtained for the shock compressibility of iron specimens with various initial densities. The resulting experimental data is used to derive the compressibility curve at absolute zero. The curve is extrapolated to pressures for which the statistical models for an atom are valid. (Authors' abstract) (Abstract in Physics Express, July 1958).

1168 Al'tshuler L V, Krupnikov K K and Brazhnik M I
THE DYNAMIC COMPRESSIBILITY OF METALS AT PRESSURES FROM FOUR HUNDRED THOUSAND TO FOUR MILLION ATMOSPHERES
Zhur. Eksper. i Teoret. Fiz. 34:886-93, No. 4, April 1958.

The paper presents a method for determining pressures and densities under conditions of shock compression. The method is based on measuring the propagation velocities for high-power shock waves. The method was used to measure the dynamic compressibility of copper, zinc, silver, cadmium, tin, gold, lead and bismuth in the pressure range 4×10^5 to 4×10^6 atm. The highest degrees of compression (2.26 and 2.28 times) were observed in zinc and bismuth (i.e., for elements with large atomic volumes). The highest absolute density (32.7 g/cm^3) was registered for gold. (Abstract in Physics Express, July 1958).

1169 Allen W A, Mapes J M and Mayfield E B
SHOCK WAVES IN AIR PRODUCED BY WAVES IN A PLATE
Journal of Applied Physics
1955, Vol. 26, pp. 1173-1175.

A shadowgraphic technique has been used to measure surface motion of a series of steel plates while they deform under impact caused by 1/2-in. diameter steel cylinders fired into their back surfaces at about 2800 ft/sec. The strength of the air shock produced when an initial longitudinal wave in a plate strikes the free surface of the plate has been inferred from the measured shock wave velocity in the air. The shock strength has been related to particle velocity of the surface of the plate. The results are compared to previous work involving contact explosions of small charges on plates. (Authors' abstract)

Chronological Listing

Year	Reference number(s)								
1958	1116	1138	1139	1161	1167	1168	1163	1165	
1957	1117	1135	5	1140	1166				
1956	1114	1136	1152						
1955	1106	1115	1118	1119	1131	1145	1146	1147	1148
	1149	1153	1169	1162					
1954	1130	1134	1141	1142	1143	1144	1151		
1953	1101	1102	1103	1105	1120	1122	1150		
1952	1109	1121	1124	1127	1128	1129			
1951	1104	1107	1108	1110	1112				
1950									
1949	1125	1132	1133						
1948	1111								
1947									
1946									
1945									
1944	1126								
1943									
1942									
1941									
1936	1113								

DYNAMIC PHOTOELASTICITY AND RELATED TOPICS
(2000-2099)

DYNAMIC PHOTOELASTICITY AND RELATED TOPICS
(2000-2099)

Bibliography

2001 Frocht M M
KINEMATOGRAPHY IN PHOTOELASTICITY
Transactions American Society of Mechanical Engineers
1932, Vol. 54, p. APM 54-9.

Moving pictures are presented showing stress fluctuations in a beam due to impact of a falling weight. Camera Speed limited to 64 frames/sec.

2002 Foeppl L
SLOW MOTION PICTURES OF IMPACT TESTS BY MEANS OF PHOTOELASTICITY
Journal of Applied Mechanics
Transactions American Society of Mechanical Engineers
1949, Vol. 71, p. 173.

Moving pictures are presented showing the stress fluctuation in beams due to the impact of a hammer. Both elastic and plastic conditions are shown. Camera speed maximum of 3020 frames/sec.

2003 Perkins H C
MOVIES OF STRESS WAVES IN PHOTOELASTIC RUBBER
Journal of Applied Mechanics, Trans. ASME
1953, Vol. 75, p. 140.

Moving pictures are presented which show stress waves propagating in photoelastic rubber specimens. Camera speed maximum of 5000 frames/sec.

2004 Frocht M M and Flynn P D
STUDIES IN DYNAMIC PHOTOELASTICITY
Journal of Applied Mechanics, Trans. ASME
1956, Vol. 78, p. 116.

Equipment and techniques are described for obtaining dynamic photoelastic stress patterns by means

of streak photography. Dynamic photoelastic stress patterns showing stress-wave propagation are given for a bar struck axially by a rigid mass. 1, 500, 000 equivalent exposures/sec.

2005 Durelli A J and Riley W E
EXPERIMENTS FOR THE DETERMINATION OF TRANSIENT STRESS AND STRAIN DISTRIBUTION IN TWO-DIMENSIONAL PROBLEMS
Journal of Applied Mechanics, Trans. ASME
1957, Vol. 79, p. 69.

A photoelastic material of low modulus of elasticity is developed for use in stress-wave propagation studies. Dynamic and static photoelastic and mechanical properties are investigated and methods are described. Photographs of fringe patterns are shown for circular discs and beams subjected to impact. Camera speed 14, 000 frames/sec.

2006 Sutton G W
A PHOTOELASTIC STUDY OF STRAIN WAVES CAUSED BY CAVITATION
Journal of Applied Mechanics, Trans. ASME
1957, Vol. 79, p. 340
Discussion Journal of Applied Mechanics
1958, Vol. 80, pp. 298-299.

Ultra-high-speed photoelastic techniques have been applied to a study of the transient stresses and strains in a photoelastic plastic when subject to cavitation. Cavitation bubbles have been photographed collapsing on the surface of a photoelastic specimen and the resulting strain wave has been photographed. The static and dynamic properties of CR-39 are determined. Camera speed 1, 000, 000 frames/sec.

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A PHOTOELASTIC STUDY OF MAXIMUM TENSILE STRESSES IN SIMPLY SUPPORTED SHORT BEAMS UNDER CENTRAL TRANSVERSE IMPACT
Journal of Applied Mechanics, Trans. ASME
1957, Vol. 79, p. 509
Discussion Journal of Applied Mechanics
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Photoelastic streak photographs were taken for beams subjected to the impact of a heavy mass. This article is primarily concerned with the interpretation of results of this study. Experimental techniques are not fully discussed.

2008 Frocht M M, Flynn P D and Landsberg D
DYNAMIC PHOTOELASTICITY BY MEANS OF STREAK PHOTOGRAPHY
Proceedings Society for Experimental Stress Analysis
1957, Vol. 14, No. 2, p. 81.

A review of literature on high-speed photography and dynamic photoelasticity is presented. Equipment and techniques for streak photography are described in detail.

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A PHOTOELASTIC STUDY OF STRESS WAVES
Philosophical Magazine
1946, Series 7, Vol. 37, pp. 463-469.

This article shows the first photographs of stress-wave propagation by photoelastic means.

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THE FUNDAMENTALS OF PHOTOELASTICITY APPLIED TO DYNAMIC STRESSES
Ninth Semi-Annual Eastern Photoelasticity Conference, 13 May 1939, p. 1-11, published by the College of Engineering, Cornell University.

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PHOTOELASTIC ANALYSIS OF IMPACT STRESS PROPAGATION IN TWO DIMENSIONS (See also 2028)
Fluid Dynamic Division, American Physical Society, Cornell University (Unpublished).

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PHOTOGRAPHIC AND KINEMATOGRAPHIC STUDY OF PHOTO-ELASTICITY
Scientific Papers of the Institution of Physical and Chemical Research
20 June 1928, Vol. 8, No. 149, pp. 247-267.

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A PHOTOELASTIC STUDY OF DYNAMIC STRESSES IN STRUCTURES
Technical Report to the U.S. Navy Bureau of Docks and Yards, U. S. Naval Civil Engineering Research and Evaluation Laboratory, Structures Research Department Port Hueneme, California, Contract No. -28149, Project Order 10703
30 June 1952.

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Scientific Papers of the Institution of Physical and Chemical Research
April 1935, Vol. 26, No. 566, pp. 277-309; also
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2015 Feder J C, Gibbons R A, Gilbert J T and Offenbacker E L
THE STUDY OF THE PROPAGATION OF STRESS WAVES BY PHOTO-ELASTICITY
Proceedings of The Society for Experimental Stress Analysis
1956, Vol. XIV, No. 1, pp. 109-122.

The propagation of stress waves in CR-39 plastic is shown. Propagation is instigated by the impact of rod and by the explosion of blasting caps in contact with the specimen. Maximum photo speed was 1.25 microsec between frames. Results are analyzed in terms of wave propagation theory.

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ON THE STRESS-OPTIC LAW UNDER IMPACT LOADINGS
Technical Report No. 3 to the Office of Ordnance Research, U.S. Army Contract DA-11-022-1609, November 1956.

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STUDIES IN DYNAMIC PHOTOELASTICITY
Ph.D. Thesis, Illinois Institute of Technology, Chicago, Illinois
June 1954.

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STUDIES IN DYNAMIC PHOTOELASTICITY: FRINGE VALVES AND BEAMS UNDER IMPACT
Ph.D , Thesis, Illinois Institute of Technology, Chicago Illinois
June 1956.

2019 Clark A B J
STATIC AND DYNAMIC CALIBRATION OF A PHOTOELASTIC MODEL MATERIAL, CR-39
Proceedings Society for Experimental Stress Analysis
1956, Vol. XIV No. 1, pp. 195-204.

2019 Clark A B J
STATIC AND DYNAMIC CALIBRATION OF A PHOTOELASTIC MODEL MATERIAL, CR-39
Proceedings Society for Experimental Stress Analysis
1956, Vol. XIV No. 1, pp. 195-204.

A thorough investigation of the properties of CR-39 is conducted. Dynamic properties are determined by passing a stress wave through the material and using a photocell to record lightness and darkness (i.e. passage of different fringes). Techniques are fully discussed and results are analyzed.

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REFLECTION OF ELASTIC WAVES FROM A FREE BOUNDARY
Philosophical Magazine,
May 1955, Vol. 46 Part 1, pp. 527-541.

The photoelastic technique is used in studying the problem of reflection of stress waves at a free boundary. Photographs shown are very clear and show the reflection very descriptively. Multiple spark camera was used which could take successive pictures at times ranging from 5 microsec to 50 microsec. Very clear photographs.

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Compt. Rend. Académie des Sciences (Paris)
1952, Vol. 234, pp. 2337-2339.

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SOME RESULTS OF THE DYNAMIC TESTING OF MATERIALS
Riv. Nuovo, Cim.,
1948, Vol. 4, pp. 1-28.

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Ann. Phys. (Leipzig)
1955, Vol. 16, pp. 119-133.

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OPTICAL POLARIZATION EXPERIMENTS ON THE ELASTIC IMPACT THEORY OF ST. VENANT AND FLAMANT
Ann. Phys. (Leipzig)
1955, Vol. 16, pp. 306-321.

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A PHOTOELASTIC STUDY OF MAXIMUM TENSILE STRESSES IN SIMPLY SUPPORTED BEAMS UNDER CENTRAL TRANVERSE IMPACT
Technical Report, OOR Contract No. DA-11-022-ORD-1609,
October 1955.

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A METHOD OF ASSESSING TRANSIENT STRESSES IN PHOTOELASTIC SUBSTANCES
Review of Scientific Instruments
1949, Vol. 20, p. 139.

A brief half page note showing a photograph as an indication that photoelasticity can be used to study transient stress phenomena.

2027 Murray W M
A PHOTOELASTIC STUDY IN VIBRATION
Journal of Applied Physics
1941, Vol. 12, pp. 617-622.

A photoelastic study of steady state vibration of a cantilever beam. Moving pictures not taken.

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PHOTOELASTIC STRESS ANALYSIS OF A SHOCK LOADED STRUCTURE
Paper presented at Meeting of the Division of Fluid Dynamics, American Physical Society, Ithaca, New York, 11-12 September 1951
Abstract in Physical Review, 1951, Vol. 84, p. 614.

> The analysis of stress propagation in solids of nonconstant section has occasioned the development of this technique, of which some of the first results are presented. High velocity moving pictures (4000 frames per second) were taken in the polariscope of specimens made out of gelatin. The specimens were struck by a hammer at various velocities between zero and 30 ft/sec_____. Moving pictures of isochromatic patterns are presented with emphasis on the boundary effects in plates of various shapes._____.

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PHOTOELASTIC STRESS ANALYSIS OF A SHOCK LOADED STRUCTURE
Paper presented at Meeting of the Division of Fluid Dynamics, American Physical Society, Ithaca, New York, 11-12 September 1951
Abstract in Physical Review, 1951, Vol. 84, p. 612
Also Princeton University Department of Physics Technical Report II-9 Contract NRO61-020, N6ORi-105.

> To study the form and intensity of the stress distributions set up inside an object subjected to a shock wave, a solid model of photoelastic Bakelite was mounted in the shock tube and the stress progressions in it analyzed by means of a conventional circular polariscope. _____(p - q) patterns were taken at 10 - 20 microsec intervals starting at the time of impact. _____.

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A STUDY OF THE APPLICATION OF PHOTOELASTICITY TO THE INVESTIGATION OF STRESS WAVES
Ph.D. Thesis, California Institute of Technology, Pasadena, California, 1955.

> A detailed account is given of the determination of the static and dynamic optical and mechanical properties of CR-39. The suitability of photoelastic techniques for investigating stress waves is analyzed very carefully.

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Transactions Society of Glass Technology
1952, Vol. 36, p. 54.

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THE FRACTURES PRODUCED IN GLASS AND PLASTICS BY THE STRESS OF WAVES
Transactions Society of Glass Technology
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A NEW PHOTOELASTIC INTERFEROMETER SUITABLE FOR STATIC AND DYNAMIC MEASUREMENTS
Proceedings Society for Experimental Stress Analysis
1954, Vol. 12, No. 1, pp. 191-202.

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THE DYNAMIC STRESS-OPTIC COEFFICIENT OF PERSPEX
Proceedings Physical Society of London
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GLASS CRACKING CAUSED BY HIGH EXPLOSIVES
Journal of Applied Physics
1952, Vol. 23, pp. 48-53.

High-speed photographs have been obtained of the fracture of glass produced by the detonation of a high explosive charge. Using photoelastic methods, the shock waves set up in the glass can also be photographed. _____. Fringe patterns not shown in data obtained.

2036 Wells A A and Post D
DYNAMIC STRESS DISTRIBUTION SURROUNDING A RUNNING CRACK, A PHOTOELASTIC ANALYSIS
Office of Technical Service, P. B. 121987.

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A STUDY IN PHOTOPLASTICITY
Proceedings of the First U. S. National Congress of Applied Mechanics, Ann Arbor, Michigan, 1952, pp. 499-502.

2038 Fried B and Shoup N H
A STUDY IN PHOTOPLASTICITY
TR No. 3, ONR Contract N7onr-330-III NR064-121, State College of Washington, May 1953.

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STUDIES OF PLASTIC DEFORMATION BY THE PHOTOPLASTIC METHOD
Proceedings Sixth Japanese National Congress of Applied Mechanics, University of Kyoto, Japan, October 1956, pp. 137-140.

A proposal is made to use celluloid to represent an elastoplastic material such as a non-strain-hardening metal, and to determine stress and strain patterns in the plastic range by photoelastic techniques. The few simple examples tested indicate that not only can the plastic stress and strain distribution be determined but also the residual stress pattern after unloading can

be found. Although the time for a complete test is relatively long, the method shows considerable promise for at least qualitative studies of elasto-plastic materials in the plastic range.

2040 Bayoumi S E A and Frankl E K
FUNDAMENTAL RELATIONS IN PHOTOPLASTICITY
British Journal of Applied Physics
October 1953, Vol. 4, pp. 306-310.

A fundamental procedure for photoplastic investigations is proposed. This consists of taking two fringe photographs of the same model, one under load, the second immediately after removal of load. The difference between fringe counts at corresponding points gives the stress difference which in elastic problems is derived from a single photograph. (From authors' summary)

2041 THEORY AND APPLICATION OF PHOTOELASTICITY IN THE ELASTO-PLASTIC REGION (German)
Zeitschrift des Vereines Deutcher Ingenieure, Düsseldorf
January 1955, Vol. 97, pp. 49-58.

2042 Monch E
THE DISPERSION OF DOUBLE REFRACTION AS A MEASURE OF PLASTICITY IN PHOTOELASTIC INVESTIGATIONS (German)
Forschungsarbeiten auf dem Gebiet des Ingenieurwesen, Berlin.

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SOME OBSERVATIONS ON PHOTOELASTIC MATERIALS STRESSED BEYOND THE ELASTIC LIMIT
Proceedings Society for Experimental Stress Analysis
1951, Vol. 8, No. 2, pp. 143-148.

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BIBLIOGRAPHY ON HIGH-SPEED PHOTOGRAPHY
Eastman Kodak Company, Rochester, New York,
September 1956. (840 references)

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Journal of the Society of Motion Picture and Television Engineers
1953, Vol. 61, pp. 749-757. (210 references)

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FURTHER STUDIES OF GLASS FRACTURE WITH HIGH-SPEED PHOTOGRAPHY
Journal of American Ceramic Society
1941, Vol. 24, pp. 131-137.

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AN INVESTIGATION OF CRACKS AND STRESS WAVES IN GLASS AND PLASTICS BY HIGH-SPEED PHOTOGRAPHY
Transactions of the Society of Glass Technology
1952, Vol. 36, pp. 74-89.

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Presented at the Spring Meeting of the Society for Experimental Stress Analysis, Los Angeles, California, April 1955.

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Glastechnische Berichte, January, March, and December 1950, Vol. 23, pp. 1-10, 67-79, and 325-336.

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A REVIEW OF THE METHODS OF HIGH-SPEED PHOTOGRAPHY
Reports of the Physical Society on Progress in Physics
1957, Vol. 20, pp. 379-432. (130 references)

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STRESSES IN CURVED BEAMS DUE TO TRANSVERSE IMPACT
Paper presented at Third U.S. National Congress of Applied Mechanics, Brown University, June 1958
Abstract in Journal of Applied Mechanics, 1958, Vol. 25, p. 167.

2052 Frocht M M and Thomson R A
STUDIES IN PHOTOPLASTICITY
Paper presented at Third U.S. National Congress of Applied Mechanics, Brown University, June 1958
Abstract in Journal of Applied Mechanics, 1958, Vol. 25, p. 173.

2053 Ellis A T
TECHNIQUES FOR PRESSURE PULSE MEASUREMENT AND HIGH-SPEED PHOTOGRAPHY IN ULTRASONIC CAVITATION
Hydrodynamics Laboratory, California Institute of Technology
Report No. 21-20, July 1955.

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REVERSIBLE PHOTOELECTRIC FRINGE COUNTING
Review of Scientific Instruments
June 1958, Vol. 29.

Simple modifications of a Fizeau interferometer are shown which give a sense of direction to the passing fringes, enabling a suitable counting system to operate reversibly. Very fast counts can be made accurately using an electronic circuit actuated by four phototubes sighted on four points in the fringe pattern. An oscilloscope display can be used for fractional fringe interpolation. (Author's abstract)

Chronological Listing

Year	Reference number(s)							
1958	2051	2054						
1957	2005	2006	2007	2008	2034	2036	2050	
1956	2004	2015	2016	2018	2019	2039	2044	
1955	2020	2023	2024	2025	2030	2041	2048	2053
1954	2017	2033						
1953	2003	2038	2040	2045				
1952	2013	2021	2031	2032	2035	2037	2047	
1951	2011	2028	2029	2043				
1950	2049							
1949	2002	2026						
1948	2022							
1946	2009							
1941	2027	2046						
1939	2010							
1935	2014							
1932	2001							
1928	2012							

PENETRATION PHENOMENA
(3000-3099)

Subtopics

Hypervelocity impact; ballistic penetration and cratering due to projectile impact.

PENETRATION PHENOMENA
(3001-3099)

Bibliography

3001 Zaid M and Paul B
MECHANICS OF HIGH SPEED PROJECTILE PERFORATION
Journal of the Franklin Institute
1957, Vol. 264, pp. 117-126.

3002 Paul B and Zaid M
NORMAL PERFORATION OF A THIN PLATE BY TRUNCATED PROJECTILES
Journal of the Franklin Institute
1958, Vol. 265, pp. 317-335.

An analytical investigation is made of the perforation of a thin plate by truncated projectiles. Solutions are presented in graphical form. The strength of the plate is assumed to be negligible, which experimental data show is accurate for high velocities. Solutions are primarily concerned with loss of projectile velocity as it passes through the plate.

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ARMOR PENETRATION SURVEY
Ordnance
January 1956, pp. 609-611.

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IMPACT PHENOMENA AT HIGH SPEEDS
Journal of Applied Physics
1956, Vol. 27, pp. 1123-1129.

A study of high speed, metal-to-metal impact in the velocity range of 1 to 5 mm/μsec using 1/8 inch diameter spherical pellets is described_____. Experiments relating to the mechanism of cratering and the perforation of thin targets are presented_____ _____. (Authors' abstract)

Projectiles given high velocities by putting a hollow cone in one face of a cylindrical explosive charge.

3005 Allen W A, Mayfield E B and Morrison H L
DYNAMICS OF A PROJECTILE PENETRATING SAND
Journal of Applied Physics
1957, Vol. 28, pp. 370-376.

The results of an experiment are presented for the case of a nonrotating projectile penetrating randomly-packed sand. Results are interpreted in terms of theories of penetration. See also article 3006.

3006 Allen W A, Mayfield E B and Morrison H L
DYNAMICS OF A PROJECTILE PENETRATING SAND, PART II
Journal of Applied Physics
1957, Vol. 28, pp. 1331-1335.

3007 Huth J H, Thompson J S and Van Valkenburg M E
SOME NEW DATA ON HIGH-SPEED IMPACT PHENOMENA
Journal of Applied Mechanics, Trans. ASME
1957, Vol. 79, pp. 65-68.

This article presents a summary of some recent experimental work aimed at evaluating the role of various physical parameters in high-speed impact phenomena. Depth of cratering in thick targets is the main interest in this investigation. Impact velocities about 10,000 fps.

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STRESSES IN PROJECTILES DURING PENETRATION
Proceedings Society for Experimental Stress Analysis
1956, Vol. 13, No. 2, pp. 167-182.

Stresses in a projectile during penetration of a thin plate are measured by attaching SR-4 type strain gages to a stationary projectile and firing a plate at the projectile. Force versus time records are obtained at velocities of from 400 to 3000 fps.

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THE NORMAL PENETRATION OF A THIN ELASTIC-PLASTIC PLATE BY A RIGHT CIRCULAR CONE
Proceedings Royal Society of Edinburg
1951-52, Vol. 63, p. 359.

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SOME OBSERVATIONS ON HIGH SPEED IMPACT
Popular Astronomy
1950, Vol. 58, pp. 458-464.

This article was presented to a meeting of the Meteoritical Society. The results of high speed impact tests are summarized as an indication of the craters formed by the impact of meteors. The meteor crater in Arizona is discussed.

3011 Birkhoff G, MacDougall D P, Pugh E M and Taylor Sir G
EXPLOSIVES WITH LINED CAVITIES
Journal of Applied Physics
1948, Vol. 19, pp. 563-582.

This article summarizes the armor penetration work performed during the World War II with shaped charges. The mechanism of penetration by the jet formed by the liner, and the slug formed by the liner is discussed. Mathematical expressions are developed for the formation of the jet and the slug. Photographs are shown of various penetrations.

3012 Gehring J W
OBSERVATIONS ON HIGH SPEED PELLETS AND THEIR IMPACT UPON TARGET PELLETS
B. R. L. Memorandum Report No. 704, 1953 (Unclassified)
Aberdeen Proving Ground, Maryland.

3013 Van Valkenburg M E
MODELING OF HIGH SPEED IMPACT THROUGH THE USE OF PLASTICS
1955, OSR Report No. 1, University of Utah.

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METHOD FOR PRODUCING HIGH-VELOCITY METALLIC AND PLASTIC PELLETS
Journal of Applied Physics
1955, Vol. 26, pp. 776.

3015 Masket A V
THE MEASUREMENT OF FORCES RESISTING ARMOR PENETRATION
Journal of Applied Physics
1949, Vol. 20, pp. 132-140.

This paper summarizes the experimental and theoretical status of the optical chronograph developed in the course of ballistic research at the Naval Research Laboratory. The instrument together with a simple procedure for analysis of data, is capable of yielding the position velocity and deceleration of a non-plastically deforming small arms projectile during armor penetration _____.
(Author's abstract)

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ULTRA-SPEED TRANSIENT DYNAMIC ANALYZER FOR MECHANICS AND BALLISTICS
Review of Scientific Instruments
1954, Vol. 25, pp. 704-711.

A photoelectronic apparatus has been developed which makes possible the continuous simultaneous measurement of the depth of penetration, the speed, and the deceleration of a nondeforming small-caliper projectile during armor penetration. The basic operating principle of the apparatus is to have the flight path of the projectile pass perpendicularly through a thin parallel light beam of uniform intensity which activates a vacuum type phototube_____.
(Authors' abstract)

Decelarations as high as 10^8 ft/sec^2 ±2%.

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CONCRETE PENETRATION
1945, OSRD 4856.

8

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AN ATTEMPT AT A THEORY OF ARMOR PENETRATION
1941, Ordnance Laboratory, Frankford Arsenal.

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SHAPES OF CRATERS FORMED IN PLASTER OF PARIS BY ULTRA-SPEED PELLETS
American Journal of Physics
1952, Vol. 20, p. 14.

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A MOMENTUM INTERPRETATION OF PENETRATION DATA
Memorial de l'artillerie Francaise
1927, Vol. 6, p. 1253.

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KERR CELL PHOTOGRAPHY OF HIGH SPEED PHENOMENA
Journal of Applied Physics
1951, Vol. 22, p. 487.

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VELOCITIES OF STEEL FRAGMENTS AFTER PERFORATION OF STEEL PLATES
Proceedings Physical Society of London
March 1951, Series B, Vol. 64, pp. 212-218.

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PENETRATION BY HIGH VELOCITY JETS I, II
Proceedings Physical Society of London
April 1951, Series B, pp. 298-310.

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CRITICAL CONSIDERATIONS OF THE DYNAMIC RESISTANCE OF A PLATE CONSISTING OF SEVERAL LAYERS, STRESSED BY IMPACT (German)
Zeitschrift für Angewandte Mathematik and Mechanik, Berlin
May 1949, Vol. 29, pp. 157-159.

The author considers two cases of impact stress in a plate consisting of several layers. _____. The author investigates the question of whether it is of advantage to divide the plate into several layers in order to reduce the impact force, decrease the deceleration of the point of impact and thereby decrease the shear stress around the impact center_____ (Abstract as it appears in Applied Mechanics Review).

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RESISTANCE TO THE PENETRATION OF A BULLET THROUGH AN ALUMINUM PLATE
Journal of the Physical Society of Japan, Tokyo
September-October 1951, Vol. 6, pp. 374-378.

3026 Heine-Geldren R V and Pugh E M
THE PHOTOGRAPHY OF HIGH-SPEED METALLIC JETS
Meteoritics
1953, Vol. 1, No. 1, pp. 5-10.

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THE FORMATION OF CRATER'S BY HIGH SPEED PARTICLES
Meteoritics
1953, Vol. 1, No. 1, pp. 11-27.

This article is a study of the craters formed by high-speed particles (>10, 000 ft/sec). The theories of Öpik are compared to the theory that has been used for lower velocities (volume of crater proportional to kinetic energy). Experimental results are shown.

Problem is well discussed.

3028 Allen W A, Mapes J M and Wilson W G
AN EFFECT PRODUCED BY OBLIQUE IMPACT OF A CYLINDER ON A THIN TARGET
Letter in Journal of Applied Physics
1954, Vol 25, pp. 675-676.

Letter to the editor describes a phenomenon observed when a circular steel cylinder is fired at ordnance velocities at thin lead targets (0. 005 - 0. 010 in).

If a critical angle of incidence of the projectile on the target is exceeded the front surface of the cylinder is marked by a series of ridges. Photographs are shown of the phenomenon.

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SURFACE ENERGY, A MODE FOR ENERGY ABSORPTION DURING IMPACT
American Journal of Physics
1953, Vol. 21, pp. 305-307.

The role that pulverization of the target material may play in absorbing the energy of an impacting missile is discussed. The energy absorbed depends upon the area of the new surfaces formed. Correlation is made to impact of meteorites.

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SURFACE FRICTION IN BALLISTIC PENETRATION
Journal of Applied Physics
1955, Vol. 26, pp 1248-1254.

The frictional adhesion between projectile and target during a ballistic penetration has been measured with a torsion-type Hopkinson bar. The apparatus allows measurement of the torsional adhesion of a spinning projectile during target penetration. By assuming the friction resisting rotation to be equal to that resisting axial penetration, the energy loss due to friction was computed. The results show that the torque time pattern during penetration of a "mechanically" clean projectile can be predicted with the assumption of a frictional energy loss just sufficient to keep the sliding surfaces at the melting temperature of the metal. Metallographic analysis of the target metal at the projectile interface gives a further indication of a molten interface. In these tests, sliding friction accounts for about 3 per cent of the striking energy of the projectile common surface contaminants, not necessarily special lubricants, reduce this loss to less than 1 per cent. (Author's abstract)

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AN APPROXIMATE THEORY OF ARMOR PENETRATION
Journal of Applied Physics
1955, Vol. 26, pp. 80-82.

The problem of armor penetration of thin plates is considered from a quasi-dynamical approach. Equations are derived for the energy dissipation due to plastic deformation and for heating of the projectile target interface. Both the conical and the ogival head are considered in the application of the general equations. (Author's abstract)

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BEHAVIOR OF METALS UNDER IMPACT LOADING AND THE MECHANISM OF CRATERING
University of Utah, Institute for the Study of Rate Processes, October 1956
Library of Congress P. B. 125534.

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MEASUREMENT OF FORCES WHICH RESIST PENETRATION OF STJ ARMOR, MOLD STEEL AND 24 ST Aluminum
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Library of Congress P. B. 120710.

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PENETRATION OF FACE-HARDENED BULLET-PROOF ARMOR BY SOLID CALIBER .27 BULLET
May 1944, U. S. Naval Research Laboratory.

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EFFECT OF YAW UPON PENETRATION: THE EFFECT UPON BULLETS PENETRATING VERY THIN DURALUMIN SHEETS; THE USE OF SHIELDING STRUCTURES IN THE FORM OF GRARRINGS. FIFTH PARTIAL REPORT ON LIGHT ARMOR
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VELOCITY LOSS OF A 1/2 INCH MODEL PROJECTILE WHEN IT PENETRATES 1/32 INCH COLD-ROLLED SHEET STEEL
March 1944, U. S. Naval Research Laboratory
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EFFECTS OF TEMPERATURE ON THE RESISTANCE TO IMPACT PENETRATION AND HARDNESS OF SOFT HOMOGENEOUS ARMOR AND FACE-HARDENED BULLET-PROOF STEEL AND A DESCRIPTION OF A NEW BASIC FEATURE OF IMPACT PENETRATION
June 1942, U. S. Naval Research Laboratory
Library of Congress P. B. 120678.

3038 Clay W G and Partridge W
WAX MODELING STUDIES OF HIGH-SPEED IMPACT
June 1956, Utah University
Library of Congress P. B. 123452.

3039 Partridge W S and Clay W G
STUDIES OF HIGH-VELOCITY IMPACT IN WAX
Journal of Applied Physics
1958, Vol. 29, No. 6, pp. 939-942.

Wax targets are used to study the condition when impact velocities are greater than the sonic velocity of the target. The penetration was found to vary linearly with the cube root of the pellet velocity up to velocities in excess of twice the sonic velocity of the target material.

3040 Backman M E
ELASTIC AND PLASTIC BEHAVIOR IN SIMPLE TARGET-PROJECTILE SYSTEMS
NAVORD Report 5593.

The dynamic interaction of steel projectiles striking aluminum alloy plates at normal incidence has been investigated for geometrically simple projectiles. Observations on the penetration craters formed by flat-nose projectiles and certain idealized stress wave considerations lead to a theory of cavity formation. This can be formulated quantitatively as the relationship of the depth of penetration to (1) impact velocity, (2) certain functions of the characteristic impedances of the target and projectile materials, and (3) an empirically determined dynamic elastic limit. This theory agrees with measurements for small projectiles traveling at velocities between 300 and 850 meters/sec. Velocity ranges of dominantly elastic and dominantly plastic target behavior can be identified. (Author's abstract)

3041 Atkins W W
FLASH ASSOCIATED WITH HIGH-VELOCITY IMPACT ON ALUMINUM
Journal of Applied Physics
1955, Vol. 26, p. 126.

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PENETRATION PHENOMENA

Chronological Listing

Year	Reference number(s)					
1958	3002	3039	3044	3045	3046	3047
1957	3001	3005	3006	3007	3040	3043
1956	3003	3004	3008	3032	3038	
1955	3013	3014	3030	3031	3041	3042
1954	3016	3028				
1953	3012	3026	3027	3029		
1952	3019					
1951	3009	3021	3022	3023	3025	
1950	3010					
1949	3015	3024				
1948	3011					
1947						
1946						
1945	2017					
1944	3033	3034	3036			
1943						
1942	3037					
1941	3018					
1939	3035					
1927	3020					

BEHAVIOR OF MATERIALS AT HIGH-STRAIN RATES (1200-1299)

Subtopic

Time delay for yielding.

BEHAVIOR OF MATERIALS AT HIGH-STRAIN RATES
(1200-1299)

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IMPACT MEASUREMENT DEVICES
(2100-2199)

IMPACT MEASUREMENT DEVICES
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Journal of Applied Mechanics, Trans. ASME
1956, Vol. 78, pp. 606-611.

An experimental investigation designed to study the phenomena incident to the oblique collision of 1/2-inch-diameter steel spheres with mild-steel and annealed drill-rod beams at oblique angles of incidence has been undertaken. Initial ball velocities ranged from 30 ft/sec to 150 ft/sec, beam sizes varied from 1/4 in. x 1/4 in. to 3/4 in. x 3/4 in., angles of incidence were chosen from 85 deg to normal incidence, and simply supported, clamped, and free beams were employed. Information is reported concerning the values of maximum bending stress at various positions along the beam as function of the angle of incidence and as a function of beam size for various angles of incidence. The progressive dispersion of the initial transient has been examined in detail. The effect of end supports, effective beam length, and repetitive shots into the same hole upon stress are described.

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The object of this paper is to consider the plastic deformation of the semi-infinite beams subject to dynamic transverse loading at the free end. The type of loading considered is that of a constant bending moment, together with a transverse force the magnitude of which is inversely proportional to the square root of time. Part 1 of the paper consists of a plastic-rigid analysis of the problem, based on the plastic-rigid analysis of infinite beams under transverse, constant velocity, impact loading developed by the author. Part 2 of the paper consists of an elastic-plastic solution of the problem, based on a theoretical analysis of the plastic deformation of infinite beams subject to transverse, constant-velocity impact loading developed by H. F. Bohenblust. Specific problems are considered for which the deflection solutions obtained by elastic ideally plastic and rigid ideally plastic analyses are compared. (Author's abstract)

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A simply supported uniform beam of ductile material, subjected to impulsive loading such that the initial velocity is a half-sine wave, is considered in this paper. The elastic and elastic-plastic motions are discussed under the assumption that plastic flow is confined to one cross section, and the final deformations are compared with those computed from an analysis which neglects all elastic deformations. The purpose of the work is to provide further information which may help in estimating the range of validity of the latter ("rigid-plastic") type of analysis. (Authors' abstract)

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IMPACT OF FINITE BEAMS OF DUCTILE MATERIAL
Journal of Mechanics and Physics of Solids
1954, Vol. 2, pp. 92-102.

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THE TRANSMISSION OF A SPHERICAL SOUND WAVE THROUGH A THIN ELASTIC PLATE
Annals of Physics
1957, Vol. 1, pp. 233-246.

4025 Alverson R C
IMPACT WITH FINITE ACCELERATION TIME ON ELASTIC AND ELASTIC-PLASTIC BEAMS
Brown University, April 1955
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TRANSVERSE WAVES IN BEAMS
Proceedings Society for Experimental Stress Analysis,
1951, Vol. 8, No. 2, pp. 69-82.

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LATERAL IMPACT ON BARS AND BEAMS
Proceedings Society for Experimental Stress Analysis
1957, Vol. 15, No. 1, pp. 171-178.

Experimental results are presented for the effect of axial load on the propagation of bending waves in slender beams. Theory is presented and compared to experimental results. Application of method to measurement of tensile load in wires by using results of this work.

4028 Goldsmith W and Cunningham D M
OBLIQUE IMPACT OF SPHERES UPON SIMPLY SUPPORTED STEEL BEAMS
Proceedings Society for Experimental Stress Analysis
1956, Vol. 14, No. 1.

4029 Alverson R C
IMPACT WITH FINITE ACCELERATION TIME ON ELASTIC AND ELASTIC-PLASTIC BEAMS
Journal of Applied Mechanics, Trans. ASME
1956, Vol. 78, pp. 411-415.

The purpose of the work described in this paper was to provide information on the elastic and plastic deformation of steel beams subjected to transverse impact. The particular impact problem treated was chosen to correspond to conditions in tests in which a beam initially at rest is struck by a massive hammer, so that a specified change of velocity is imposed at a certain cross section in a small time interval. In the present analysis the initial elastic and subsequent elastic-plastic motions were obtained by methods similar to those used by Bleich and Salvadori (3). As in (3), it is assumed that plastic deformation occurs only at a single stationary plastic hinge (in this case at the struck cross section). Results obtained are compared with those of a "rigid-plastic" solution of the same problem, in which plasticity conditions are correctly taken into account but elastic vibrations are not included.

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TRANSVERSE IMPACT TRANSIENTS
Proceedings Society for Experimental Stress Analysis
1943, Vol. 1, No. 2, pp. 1-10.

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LATERAL VIBRATION AND STRESS IN A BEAM UNDER SHOCK MACHINE LOADING
Proceedings Society for Experimental Stress Analysis
1947, Vol. V, No. 1, pp. 78-89.

4032 Locklin/Mills
DYNAMIC RESPONSE OF THIN BEAMS TO AIR BLAST
Ballistic Research Laboratories, Report No. 787.

This paper presents a comparison of the theoretically predicted and observed elastic responses of thin simply supported beams and of cantilever beams to air-blast loading. The theoretical responses are predicted from the linear "small-deflection" beam theory and compared to motions observed with a high-speed motion picture camera. The agreement of observed deflections with predicted ones is adequate for the thicker beams where the deflections were small, but inadequate for the thinner beams where the deflections were large. (Authors' abstract)

4033 Harris J I
LARGE DEFLECTIONS OF NON-UNIFORM ELASTIC BEAMS SUBJECTED TO TRANSIENT LOADS
Ballistic Research Laboratories, APG, Memo Report No. 1105, October 1957.

This report presents a method of solving the non-linear equation for large flexing motions of thin beams subjected to transient loads. The small deflection linearized equation is solved by successive approximation, and this solution is extended to large deflections by a perturbation scheme. The solution shows that the apparent dynamic load on any normal mode is not equal to the applied load. Because no experimental results on non-uniform beams are available, large deflections for a uniform cantilevered beam are predicted from the general solution and compared with experimental results. Agreement between experimental results and the general solution is better than that between experiment and the predictions from the solution of the linearized equations. (Author's abstract)

4034 Baker W E and Allen F J
THE DAMPING OF TRANSVERSE VIBRATIONS OF THIN BEAMS IN AIR
Ballistic Research Laboratories, APG, BRL Report No. 1033 October 1957.

A non-linear partial differential equation describing the free transverse vibration of thin beams in air is formulated. The equation accounts for two types of force on the beam caused by its motion through the air and for the force caused by internal friction of the beam material, in addition to the usual elastic and inertia forces. An approximate solution to the equation is obtained by a perturbation method.

A series of experiments were conducted at large initial vibration amplitude to corroborate the theory, which predicts that "pressure drag" air damping is proportional to amplitude and that "viscous drag" air damping and internal damping are independent of amplitude. The dependence of pressure drag damping on air pressure is also predicted. The experimental results show reasonable agreement with the theory; however, the importance of viscous air drag damping relative to that of internal friction cannot be determined. (Authors' abstract)

4035 Allen F J
AN ELASTIC-PLASTIC THEORY OF THE RESPONSE OF CANTILEVERS TO AIR BLAST LOADING
Ballistic Research Laboratories, Memorandum Report No. 886.

An elastic-plastic theory of the response of cantilevers loaded by air blast waves is proposed and the predictions obtained from it are compared to experimental results. The theory is capable of providing estimates for the types of beams considered; it is expected to furnish more precise estimates for certain other beams of practical interest.

A method is developed by means of which a high speed digital computing machine can rapidly and accurately predict dynamic elastic strains, moments, and deflections in certain structures. (Author's abstract)

4036 Allen F J and Rally F
A PLASTIC-RIGID THEORY OF THE RESPONSE OF BEAMS TO AIR BLAST LOADING
Ballistic Research Laboratories, Memorandum Report No. 811.

This report presents a "plastic-rigid" theory of cantilever and simply-supported beams subjected to air blast loading. The equations of motion are derived and the theoretical deformations found. Theoretically predicted permanent deformations are compared to experimentally determined permanent deformations of thin rectangular cross-section metal beams subjected to air blast load. The theory predicts correctly the occurrence of localized regions of plastic deformation, but does not accurately predict the amount of this deformation. However, the results suggest a modification of the theory which is expected to be in better agreement with experiment. Authors' abstract)

4037 Plass H J
SOME SOLUTIONS OF THE TIMOSHENKO BEAM EQUATION FOR SHORT PULSE-TYPE LOADING
Journal of Applied Mechanics, Trans. ASME
1958 Vol. 80, pp. 379-385.

A collection of solutions to the Timoshenko beam equation is presented. Various types of support conditions and impact conditions are included. In every case the impact is assumed to be a pulse in the form of a half-sine wave. The results were found numerically, using the method of characteristics, except for one case, which was done in addition by the Laplace transform method, for check purposes. Agreement with experiment is good except for a pulse of duration comparable to the time required for the bending-type wave to travel a distance of one diameter. Discussion is included of the differences among the various cases studied. (Author's abstract)

4038 Abramson H N
FLEXURAL WAVES IN ELASTIC BEAMS OF CIRCULAR CROSS SECTION
Journal of the Acoustical Society of America
1957, Vol. 29, pp. 42-46.

The exact equations of elasticity are employed in an investigation of the flexural vibrations of a solid circular cylinder. Contrary to previous work, it is shown that the phase-velocity-wavelength relation has an infinity of branches, thus overcoming objections, on physical grounds, which have been made to the earlier work. The three lowest branches of this dispersion relation are calculated, and these are used to study the rate of energy transmission in terms of group velocity. (Author's abstract)

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PULSE GENERATOR BASED ON HIGH SHOCK DEMAGNETIZATION OF FERROMAGNETIC MATERIAL
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SHOCK SPECTRUM AS A CRITERION OF SEVERITY OF SHOCK IMPULSES
Journal of the Acoustical Society of America
1957, Vol. 29, Part 1, pp. 596-602.

Shock impulses have not as yet yielded to any practical method of spectral analysis that would permit convenient exact calculation of all the peak internal responses of hardware subject to such accelerations, and also permit comparison of shock severities by inspection. The shock spectrum with a few supplementary techniques, provides adequate insight into the responses of a one degree of freedom resonator. As an indication of the responses of a system with several coupled degrees of freedom, a second-order shock spectrum is defined. An oscillatory constituent of the spectrum is also defined in such a way as to be applicable to any order of spectrum. Investigation of these two concepts leads to the conclusion that if the first-order shock spectrum technique is to be used as a basis for comparison of the severity of a laboratory test shock with that of a service shock, spectra should be plotted for both positive and negative directions. Moreover, when feasible, such spectra should ordinarily be plotted as distinct curves for the intervals during and after the test shock, and the oscillatory constituent for the interval during the shock should be estimated. (Authors' abstract)

5003 Conn W M
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Zeitschrift für Angewandte Physik
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Journal of Applied Physics
1953, Vol. 24, pp. 349-359.

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A STUDY OF SOME IMPACTS BETWEEN METAL BODIES BY A PIEZOELECTRIC METHOD
Proceedings Royal Society of London,
1952, Series A, Vol. 212, pp. 377-390.

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Journal of Applied Mechanics, Trans. ASME
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ELASTIC WAVES CREATED DURING TENSILE FRACTURE
Journal of Applied Mechanics, Trans. ASME
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EFFECT OF PULSE SHAPE ON SIMPLE SYSTEMS UNDER IMPULSIVE LOADING
Transactions American Society of Mechanical Engineers
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APPLICATION OF ST. VENANT'S PRINCIPLE IN DYNAMICAL PROBLEMS
Journal of Applied Mechanics, Trans. ASME
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5010 Schmitt A F
A METHOD OF STEPWISE INTEGRATION IN PROBLEMS OF IMPACT BUCKLING
Journal of Applied Mechanics, Trans. ASME
1956, Vol. 78, p. 291.

The equations for the dynamic buckling of an axially impacted column are discussed. A method is presented for the calculation of approximate load and deflection variations in problems of high-velocity impact. The method may be extended for cases wherein the stresses exceed the elastic limit. Results of calculations are presented for two cases. In one of these, agreement with a previous exact solution is found to be good. (Author's abstract)

5011 Yoh-Han Pao
EXTENSION OF THE HERTZ THEORY OF IMPACT TO THE VISCO-ELASTIC CASE
Journal of Applied Physics
1955, Vol. 26, pp. 1083-1088.

The problem considered is that of two bodies coming into normal contact over smooth curved surfaces. The initial relative velocity and the total kinetic energy involved is low. Contact is, however, confined to such small volumes of the objects involved that very high concentrations of energies are obtained at those places. The rates of application of stress are correspondingly high. The Hertz solution to this type of problem provides a useful approximation in the case of elastic objects.

In the present treatment one of the impinging bodies is of viscoelastic material. Two viscoelastic bodies may also be treated if they are of the same material. The Laplace transform method is used to obtain the visco-elastic expression for the force developed between the two surfaces. This expression is then applied to the impact case. The expression can also be applied to other truly static cases; e.g., contact between gear tooth surfaces.

The results are of technological interest, since it is not possible to say if a plastic is suitable for a certain category of impact applications, unless the rates of straining or stressing obtained in those applications can be estimated. (Author's abstract)

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THE EQUIVALENT STATIC ACCELERATION OF SHOCK MOTIONS
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Proceedings Royal Society of London,
1949, Series A, Vol. 197, pp. 416-432.

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Proceedings Society for Experimental Stress Analysis
1955, Vol. 12, No. 2, pp. 173-180.

The longitudinal impact of cylindrical bars results in a rapid strain fluctuation superimposed upon a constant strain. These transient fluctuations are eliminated by cushioning the impact surfaces with grease or solder. Magnetostriction is also shown to be partly responsible.

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PROPERTIES OF BOLTS UNDER SHOCK LOADING
Proceedings Society for Experimental Stress Analysis
1952, Vol. 10, No. 1, pp. 165-178.

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PREDICTION OF STRESSES IN A STRUCTURE UNDER AN ARBITRARY DYNAMIC LOADING
Proceedings Society for Experimental Stress Analysis
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A METHOD OF CALCULATING ENERGY LOSSES DURING IMPACT
Journal of Applied Mechanics, Trans. ASME
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MOTION AND STRESS OF AN ELASTIC CABLE DUE TO IMPACT
Journal of Applied Mechanics, Trans. ASME
1957, Vol. 79, p. 417.

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INFLUENCE OF BLAST CHARACTERISTICS ON THE FINAL DEFORMATION OF CIRCULAR CYLINDRICAL SHELLS
Journal of Applied Mechanics, Trans. ASME
1956, Vol. 78, p. 617.

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PROPAGATION OF A SUDDEN ROTATIONAL DISTURBANCE IN AN ELASTIC PLATE IN PLANE STRESS
Journal of Applied Mechanics, Trans. ASME
1956, Vol. 78, pp. 284-286.

Detailed results are found for two plane-stress problems of an elastic plate with a hole from which a symmetrical distrubance is propagated. In the first a uniform shear stress is suddenly applied and maintained at the hole. In the second a uniform (rotary) velocity is suddenly applied and maintained. The subsequent motion is entirely rotary and involves shear stress only. The problems are mathematically analogous to those of symmetrical pressure and radial velocity at the hole, already solved by Kromm, and his analysis is followed. The existence of a similar analogy in the statistical cases is well known. (Author's abstract)

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RESPONSE OF AN ELASTIC SHELL TO TRANSVERSE STEP SHOCK WAVE
Journal of Applied Mechanics, Trans. ASME
1953, Vol. 75, p. 589.

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FRACTURE OF GLASS BY SPHERICAL INDENTERS
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DETERMINATION OF THE EFFECT OF GROUND IMPACT FORCES IN THE AIRPLANE DROP TEST
Proceedings Society for Experimental Stress Analysis
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Proceedings Society for Experimental Stress Analysis
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5037 Nisbet J S and Brennan J N
SOME SECONDARY EFFECTS RELATED TO IMPACT WAVE FORMS
Journal of the Acoustical Society of America
1957, Vol. 29, pp. 837-842.

This paper is a theoretical analysis of simple structures under various types of applied impact. The results are presented from the standpoint of a static acceleration which would be required to produce the same maximum response in an undamped single degree of freedom system.

Reference is made to similar work by Frankland Proceedings SESA, 1948, Vol. VI, No. 2, pp. 7-27.

5038 Gerard G and Becker H
COLUMN BEHAVIOR UNDER CONDITIONS OF IMPACT
Journal of the Aeronautical Sciences
1952, Vol. 19, pp. 58-60.

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Journal of the Aeronautical Sciences
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Journal of Applied Mechanics, Trans. ASME
1954, Vol. 76, pp. 371-380.

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CONDITION OF HIGH-VELOCITY DUCTILE FRACTURE
Journal of Applied Physics
1955, Vol. 26, pp. 900-902.

The Griffith energy criterion, $dW = -dU$ (dW = crack propagation work, $-dU$ = released elastic energy), cannot be applied to essentially ductile fractures. In particular, it does not represent the condition of rapid ductile fracture propelled by the elastic energy of the specimen. The condition of such fractures is $d^2W/dx^2 = -d^2U/dx^2$, where x is the plastic extension accompanying the propagation of the crack.
(Author's abstract)

5043 Fung Y C and Barton M V
SOME SHOCK SPECTRA CHARACTERISTICS AND USES
Journal of Applied Mechanics, Trans. ASME
Vol. 80, pp. 365-372.

5044 Flynn P D
ELASTIC RESPONSE OF SIMPLE STRUCTURES TO PULSE LOADING
Ballistic Research Laboratories, Memorandum Report No. 525.

This paper deals with the elastic response of some simple structures subjected to a pulse loading. The structures considered are the mass on a spring, the simply supported beam, the cantilever, the circular membrane, and the clamped circular plate. The loading considered is that of a triangular pulse of pressure uniformly distributed over the area of the structural normal to the direction of motion. The pressure jumps to its peak value instantaneously and falls off linearly with increase in time, reaching

the value zero at the end of the pulse. Initially the structures are at rest and have no displacement.

The case of the simply supported beam is treated in some detail in order to illustrate the method of solution. In the other cases only the conditions necessary to specify the problem and the corresponding solutions for the deflection and strain as functions of the spatial argument and time are given. A numerical example is worked out for the simply supported beam, and the curves of deflection-time and strain-time are given for both during and after the pulse. A method is developed whereby the solutions for the triangular pulse may be modified to give directly the response of the structures to a general pressure-time loading. (Author's abstract)

5045 Baker W E and Allen F J
THE RESPONSE OF ELASTIC SPHERICAL SHELLS TO SPHERICALLY SYMMETRIC INTERNAL BLAST LOADING
Ballistic Research Laboratories, APG, BRLM Report No. 1113, August 1957.

This report presents the results of an analytical study of the reaction of an idealized nuclear reactor containment shell to internal transient loading which could be caused by reactor runaway.

The containment shell is assumed to be an elastic hollow sphere, and the transient loading is assumed spherically symmetric. A general theory of the response, valid for shells of any thickness, is developed. The theory is approximated for thin shells, and compared with experiment. The experiments corroborate the theoretical predictions. (Authors' abstract)

5046 Cunningham D M and Goldsmith W
SHORT-TIME IMPULSES PRODUCED BY LONGITUDINAL IMPACT
Paper presented at Spring Meeting of the Society for Experimental Stress Analysis, held May 14-16, 1958.

A program for the precise measurement of pulses in narrow rectangular bars generated by longitudinal impact of a 1/2-inch diameter steel ball was executed. The pulses were detected by means of resistance wire strain gages of various lengths and sandwiched piezoelectric quartz crystals, and were compared to the measured change of momentum of both ball and bar. An initial impact velocity up to 190 ft/sec always yielded permanent dents in the bar at the contact point with a depth small compared to the ball radius. Rise times of the order of 10 microseconds and peak forces of about 9,500 pounds were produced. No significant difference in the pulse shapes was observed from the records of wire-resistance strain gages and crystals,

but gages are considerably more convenient to use and are more universal in application. The impulses for longitudinal and transverse impact under similar geometric conditions appear to be comparable. (Authors' abstract)

5047 Mason P
HIGH-SPEED FRACTURE IN RUBBER
Journal of Applied Physics
1958, Vol. 29, pp. 1146-1150.

Cinematographic observations have been made of crack propagation under well-defined boundary conditions in rubbers at speeds up to 30 m/sec. The fracture markings showed resemblances to those obtained with metals, plastics, and glass, and could be related directly to the corresponding speed of fracture-propagation. In close analogy with Schardin's observations on glass, a noncrystallizing rubber (GR-S) showed a mode of crack propagation in which the fractured surfaces were visually smooth and the speed was about one quarter of the speed of longitudinal elastic waves. A crystallizing rubber (natural rubber) did not show this mode of propagation under the present test conditions. It is suggested that the modes of solid fracture can be usefully classified in three categories: (i) slow propagation, generally with smooth surfaces, obtained by careful control of the boundary conditions; (ii) propagation at intermediate rates with rough surfaces, involving correspondingly greater energy consumption; and (iii) fast propagation with smooth surfaces, the rate of propagation being limited by the speed of elastic waves in the material in accord with Mott's theory. (Author's abstract)

AUTHOR INDEX

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